US009449840B1

(12) United States Patent
Ban et al.

(10) **Patent No.: US 9,449,840 B1**

(45) **Date of Patent: Sep. 20, 2016**

(54) **METHODS OF FORMING DIFFERENT SIZED PATTERNS**

(71) Applicant: **SK hynix Inc.**, Gyeonggi-do (KR)

(72) Inventors: **Keun Do Ban**, Gyeonggi-do (KR); **Jong Cheon Park**, Gyeonggi-do (KR); **Jung Gun Heo**, Daejeon (KR); **Hong Ik Kim**, Gyeonggi-do (KR); **Cheol Kyu Bok**, Seoul (KR)

(73) Assignee: **SK Hynix Inc.**, Gyeonggi-do (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/850,419**

(22) Filed: **Sep. 10, 2015**

(30) **Foreign Application Priority Data**

Apr. 6, 2015 (KR) 10-2015-0048672

(51) **Int. Cl.**

H01L 21/02	(2006.01)
H01L 21/033	(2006.01)
H01L 21/311	(2006.01)

(52) **U.S. Cl.**

CPC ... ***H01L 21/31144*** (2013.01); ***H01L 21/02118*** (2013.01); ***H01L 21/02318*** (2013.01); ***H01L 21/0338*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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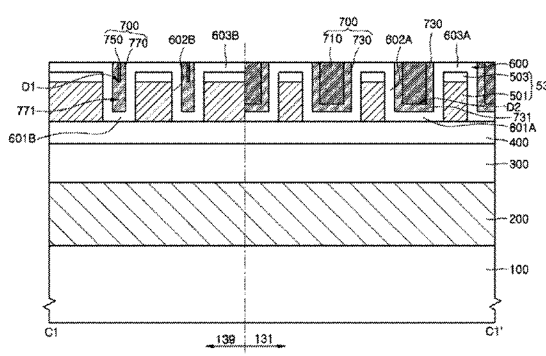
Primary Examiner — Asok K Sarkar

(74) *Attorney, Agent, or Firm* — I P & T Group LLP

(57) **ABSTRACT**

A method includes forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer; forming a separation wall layer including first separation wall portions surrounding sidewalls of the pillars, and forming second separation wall portions covering sidewalls of the first opening trench portion; forming a block copolymer layer on the separation wall layer; forming first domains in gaps between the pillars, and forming second domains surrounding and separating the first domains by annealing the block copolymer layer; forming second openings by selectively removing the first domains; forming third openings between the second openings, and forming a fourth opening adjacent to the first isolated pattern by selectively removing the pillars and the template portion; and forming fifth openings, which extend from the second and third openings and penetrate the underlying layer, and forming a sixth opening, which extends from the fourth opening and penetrates the underlying layer.

20 Claims, 53 Drawing Sheets



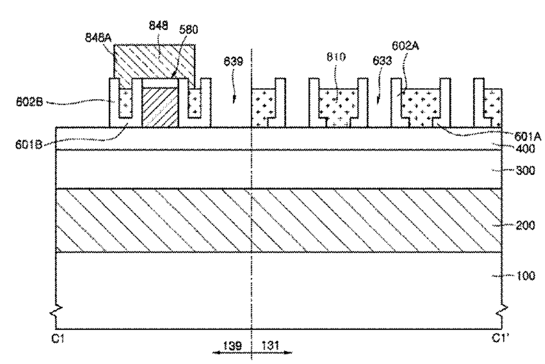


FIG. 1

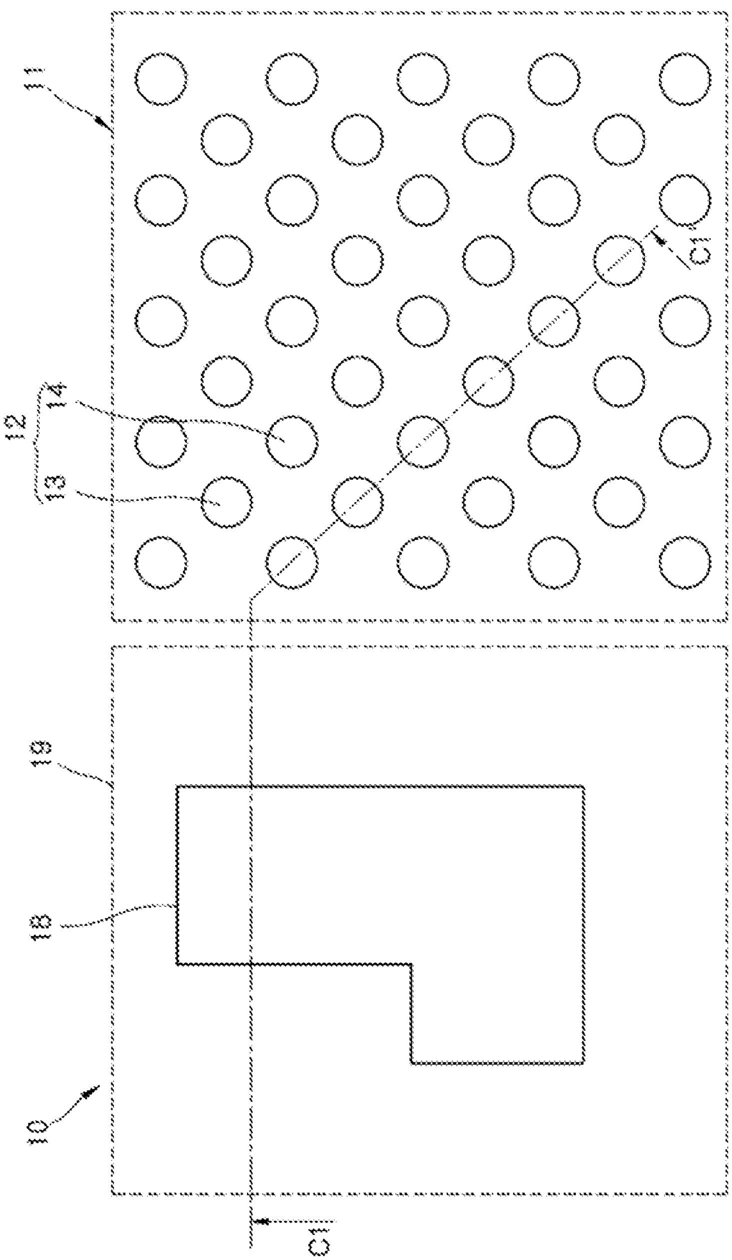


FIG. 2

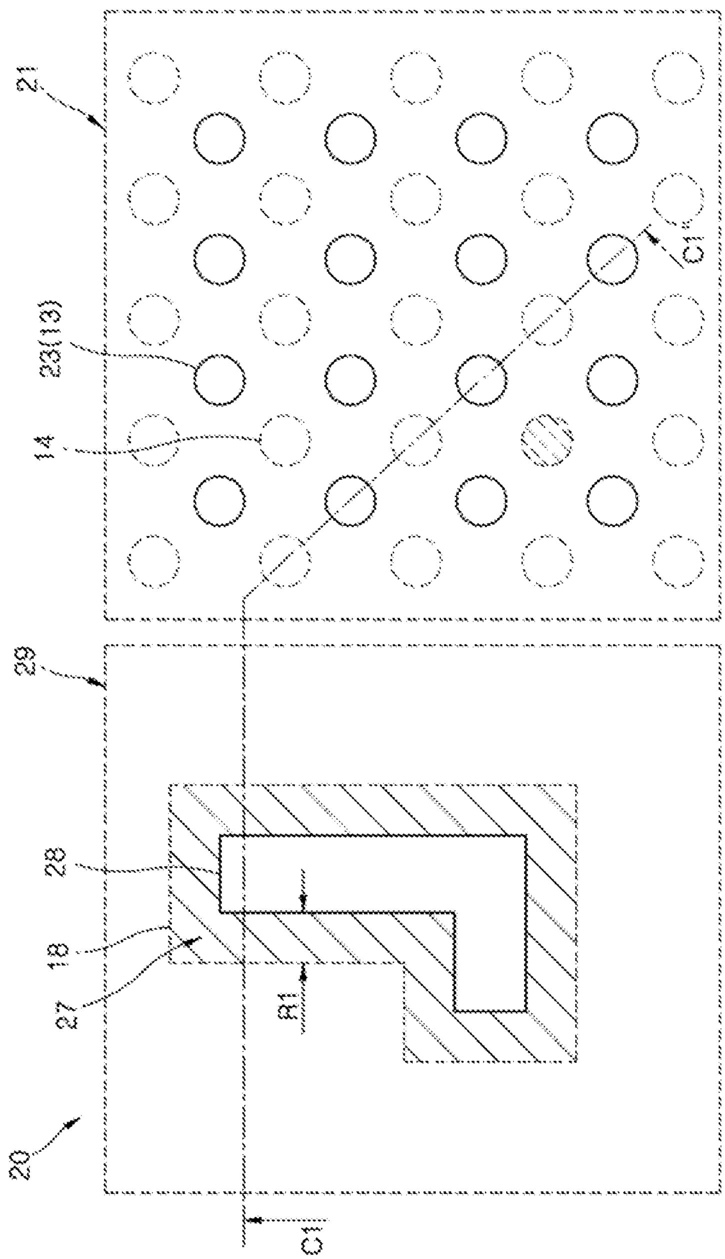


FIG. 3

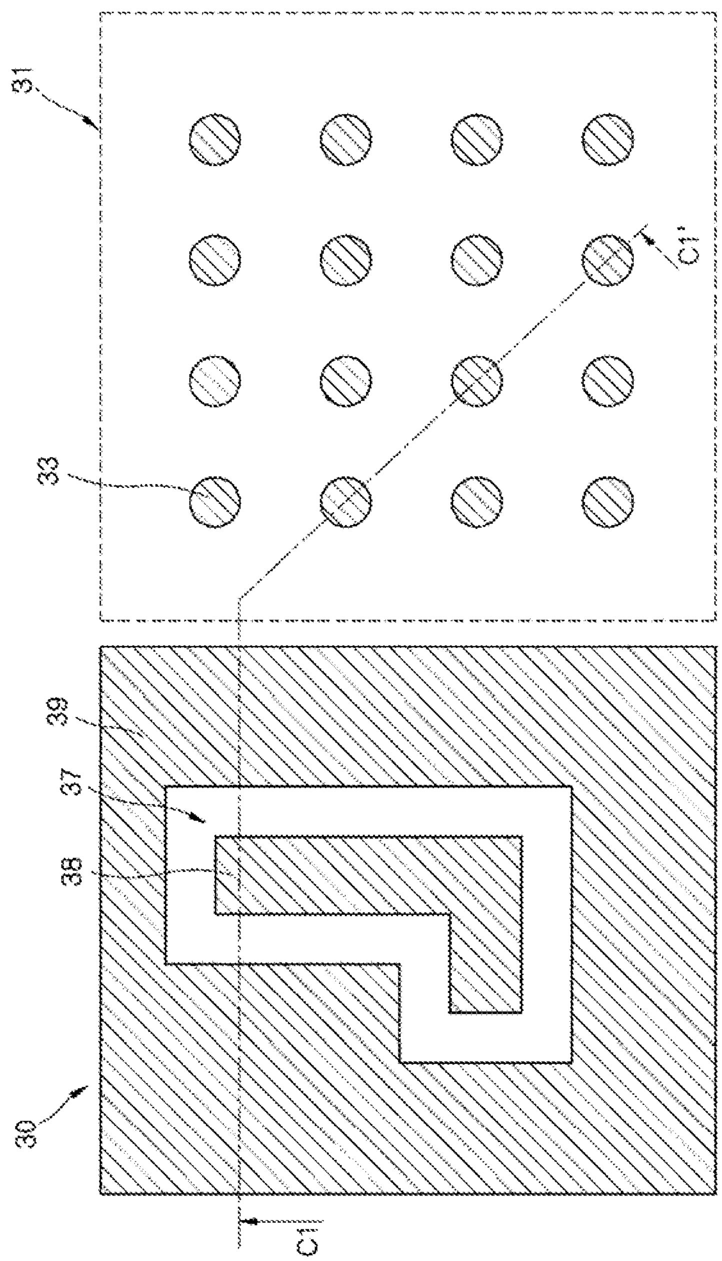


FIG. 4

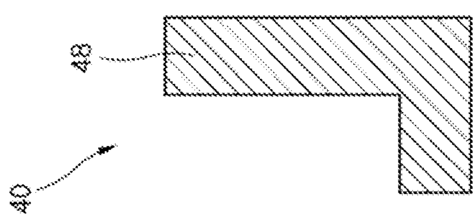


FIG. 5

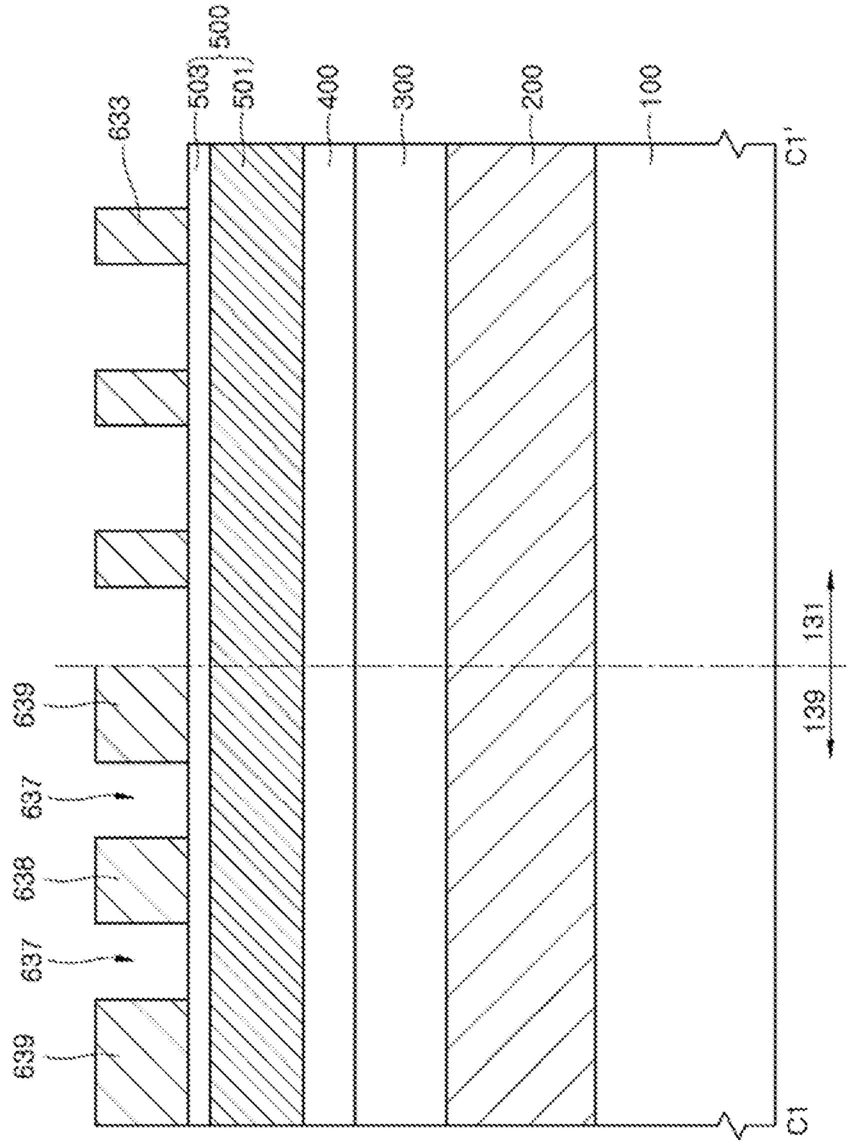


FIG. 6

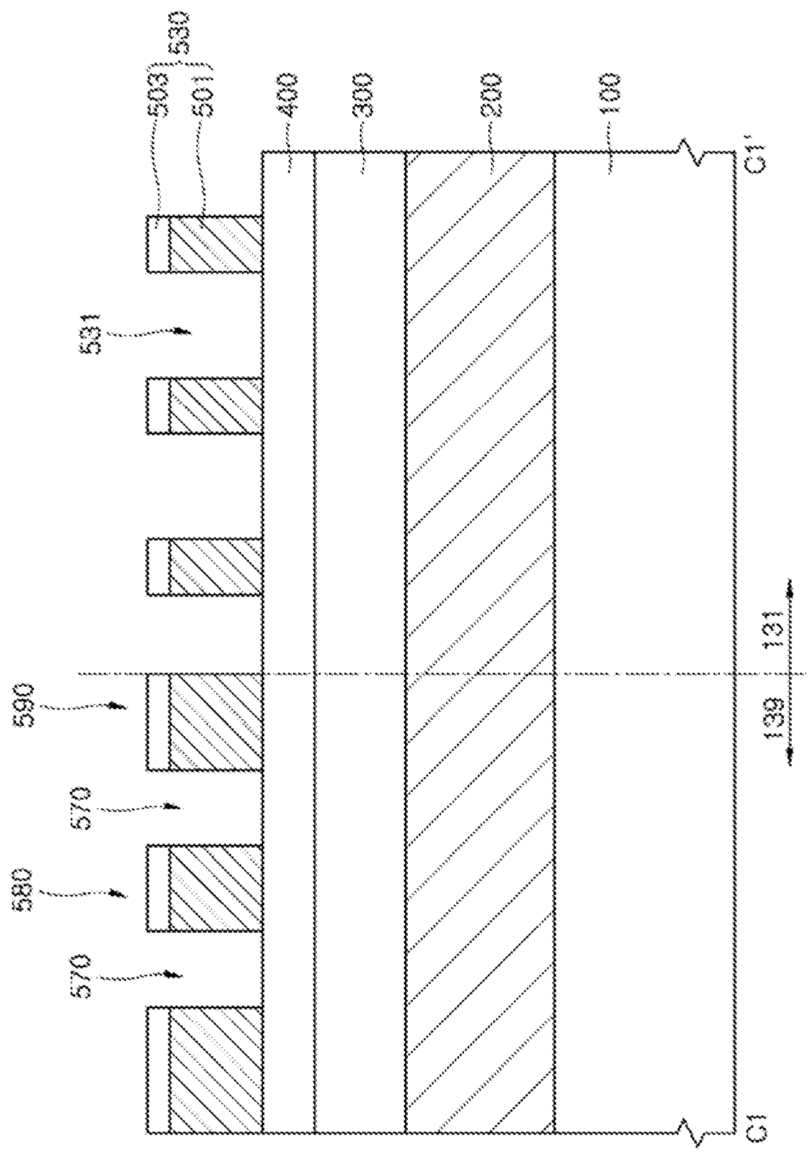
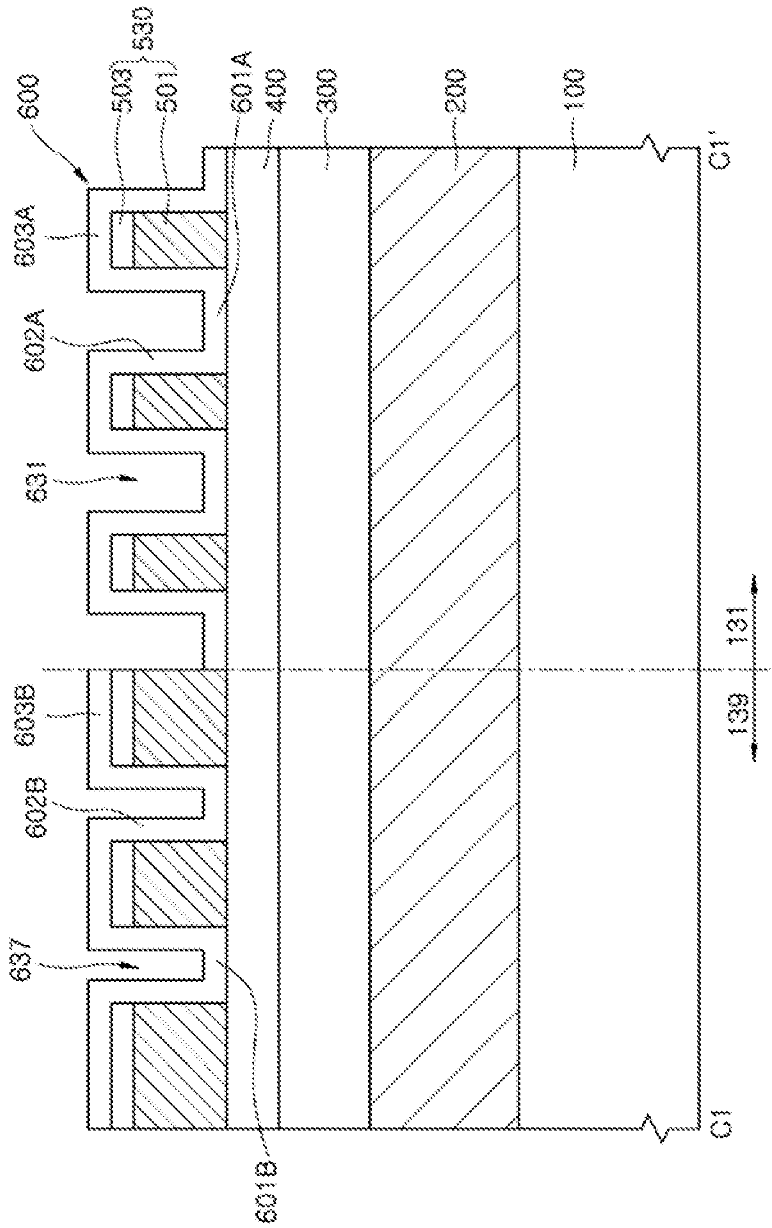


FIG. 7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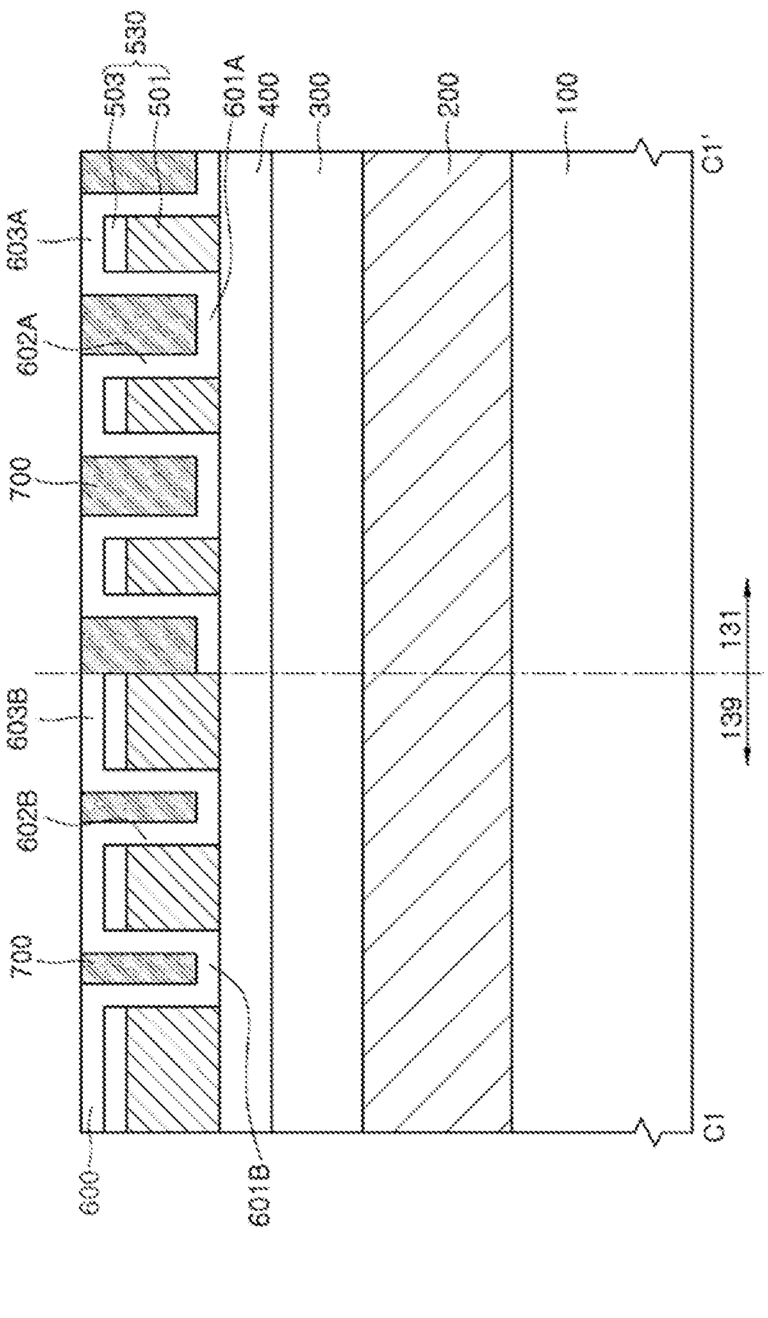
503
501
530
601A
400
300
200
100
C1'
603A
602A
631
603B
602B
637
601B
C1
131
139

FIG. 8



530
503
501
601A
400
300
200
100
C1'
603A
602A
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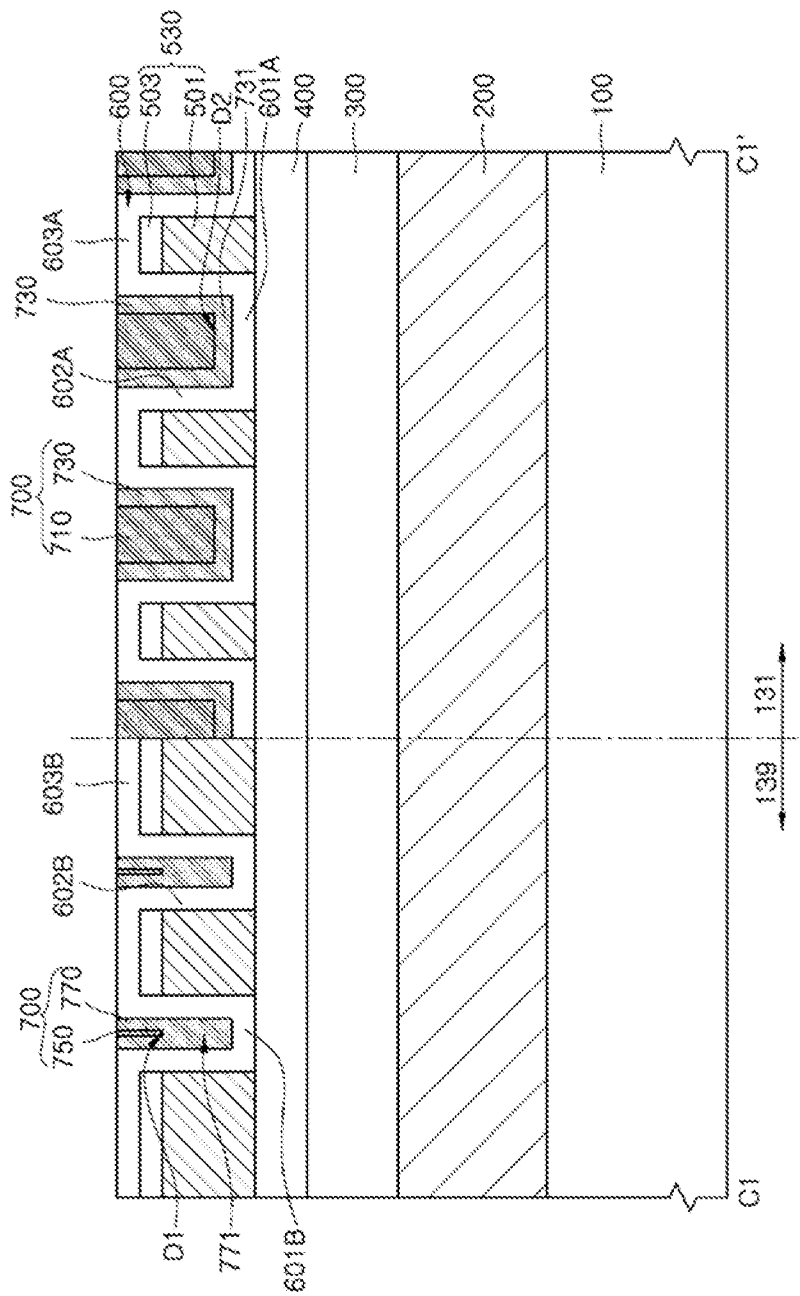
603B
602B
700
600
601B
C1
131
139

FIG. 9



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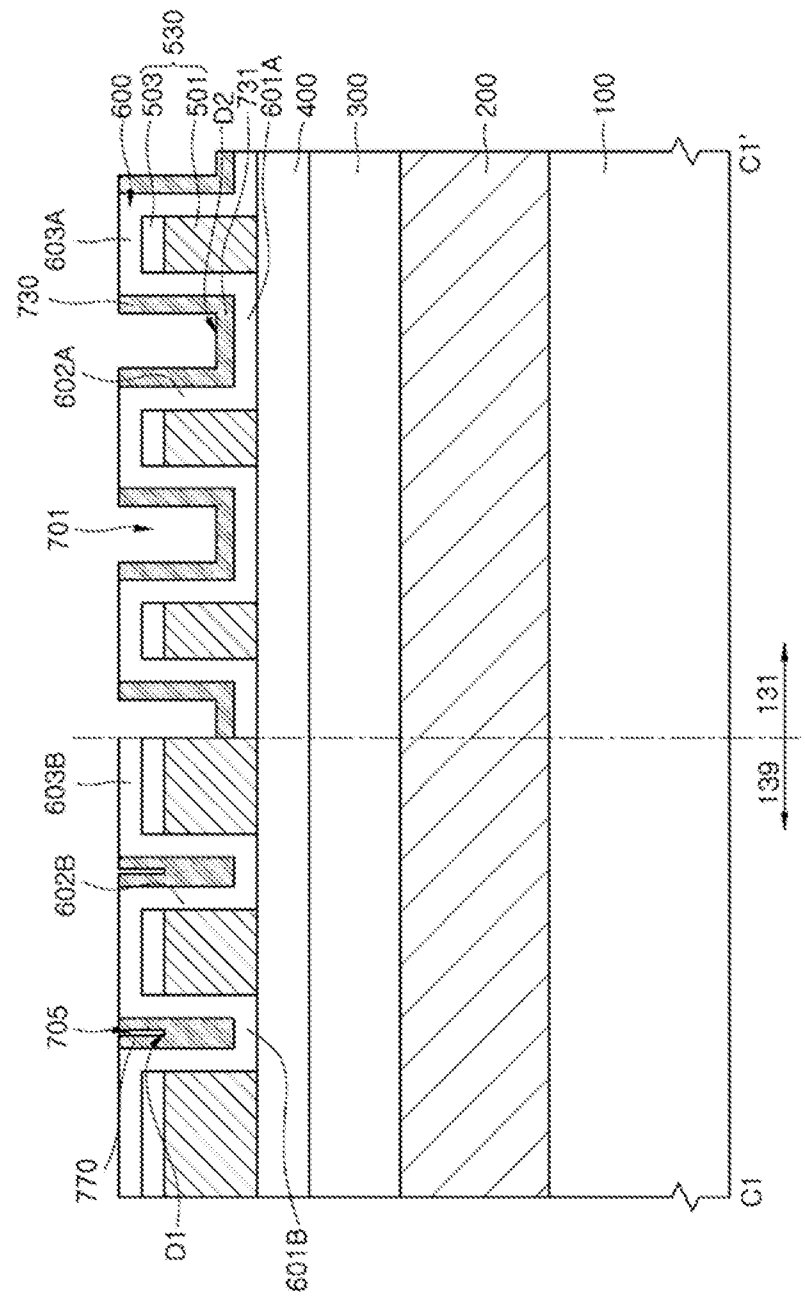
503
501
530
D2
731
601A
400
300
200
100
C1'
603A
730
602A
700
730
710
603B
602B
700
770
750
131
139
D1
771
601B
C1

FIG. 10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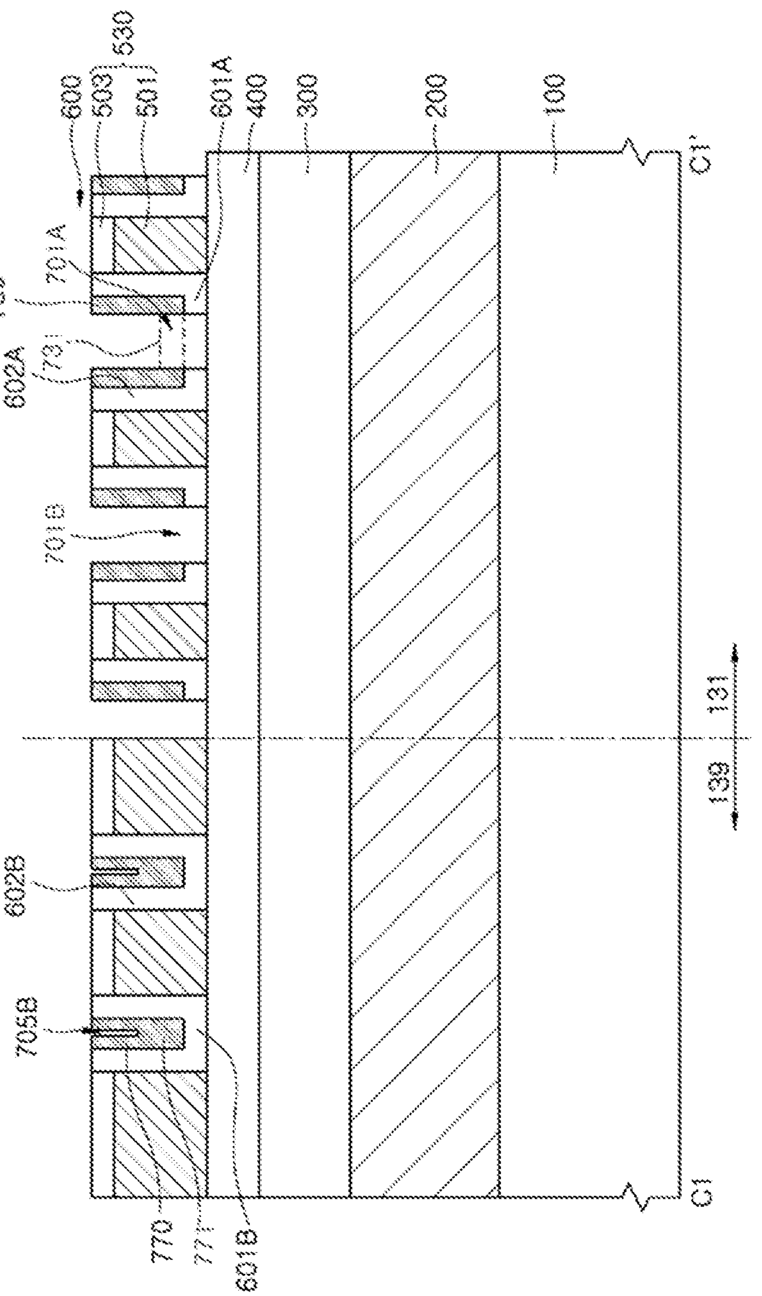
503
501
530
D2
731
601A
400
300
200
100
C1'
603A
730
602A
701
603B
602B
705
770
D1
601B
C1
131
139

FIG. 11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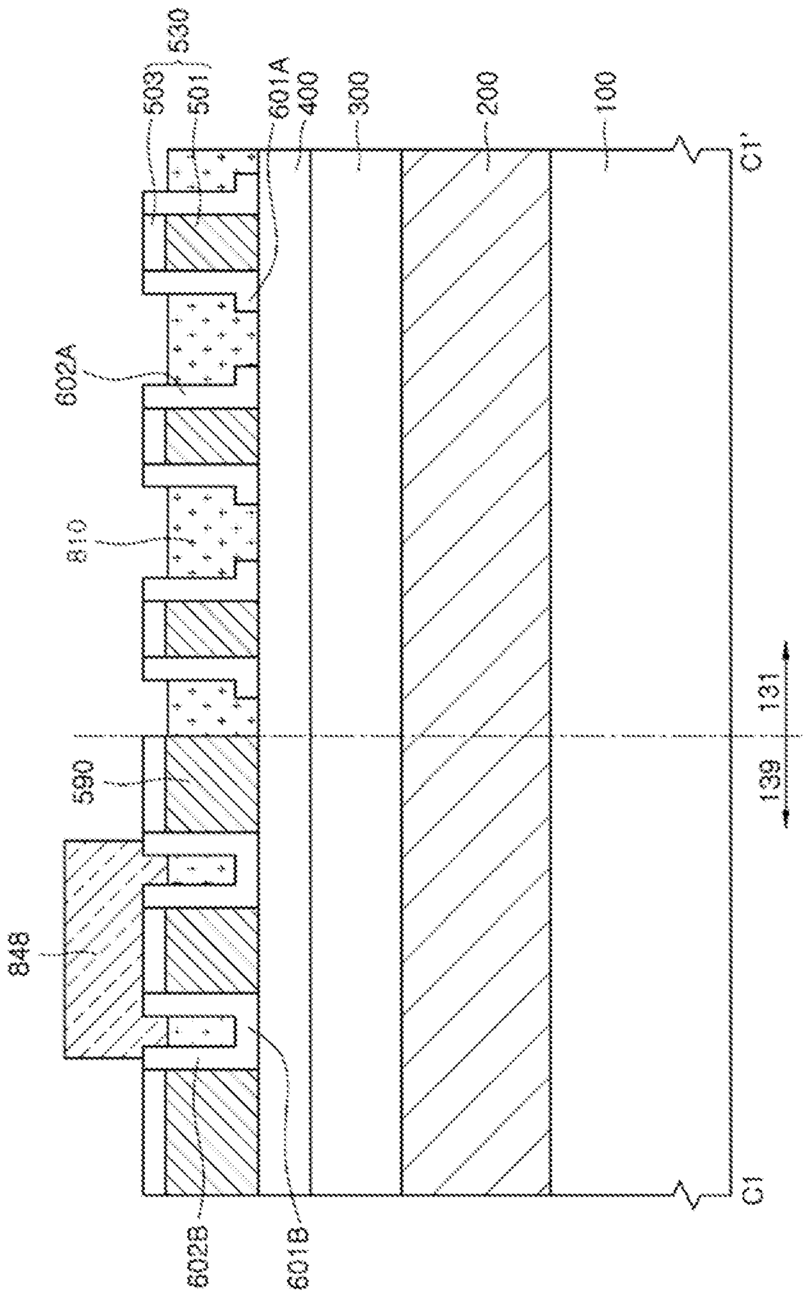
503
501
530
601A
400
300
200
100
C1'
730
701A
731
602A
701B
131
139
602B
705B
770
771
601B
C1

FIG. 12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503
501
601A
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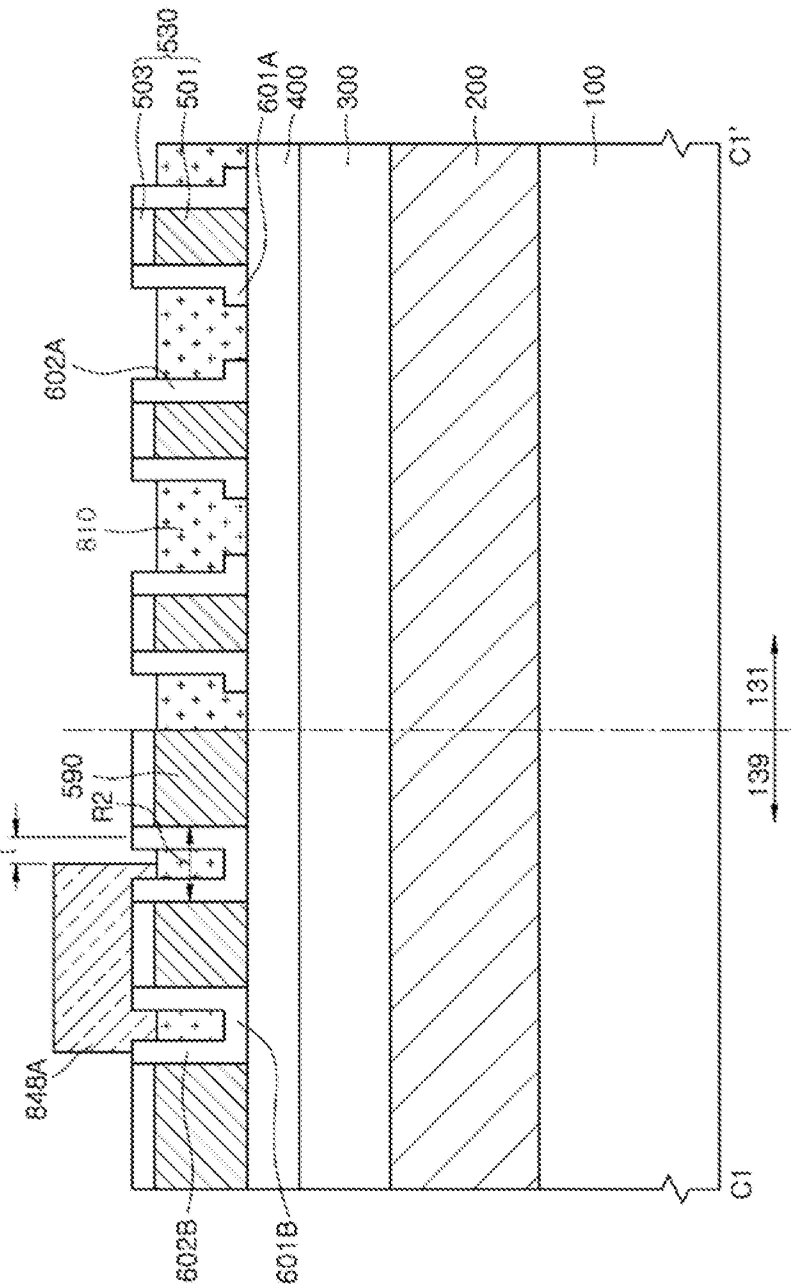
300
200
100
C1'
602A
810
131
139
590
848
602B
601B
C1

FIG. 13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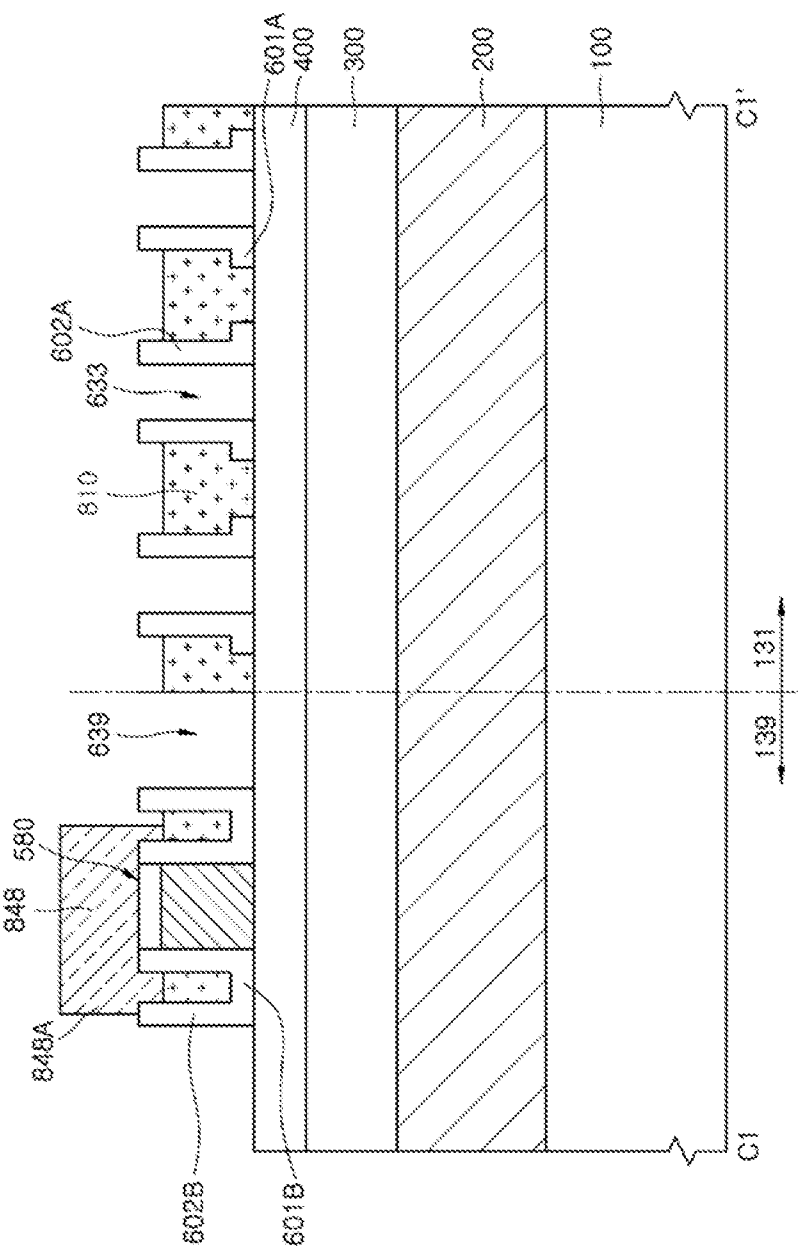
503
501
601A
400
300
200
100
C1'
602A
810
131
139
590
R2
S
848A
602B
601B
C1

FIG. 14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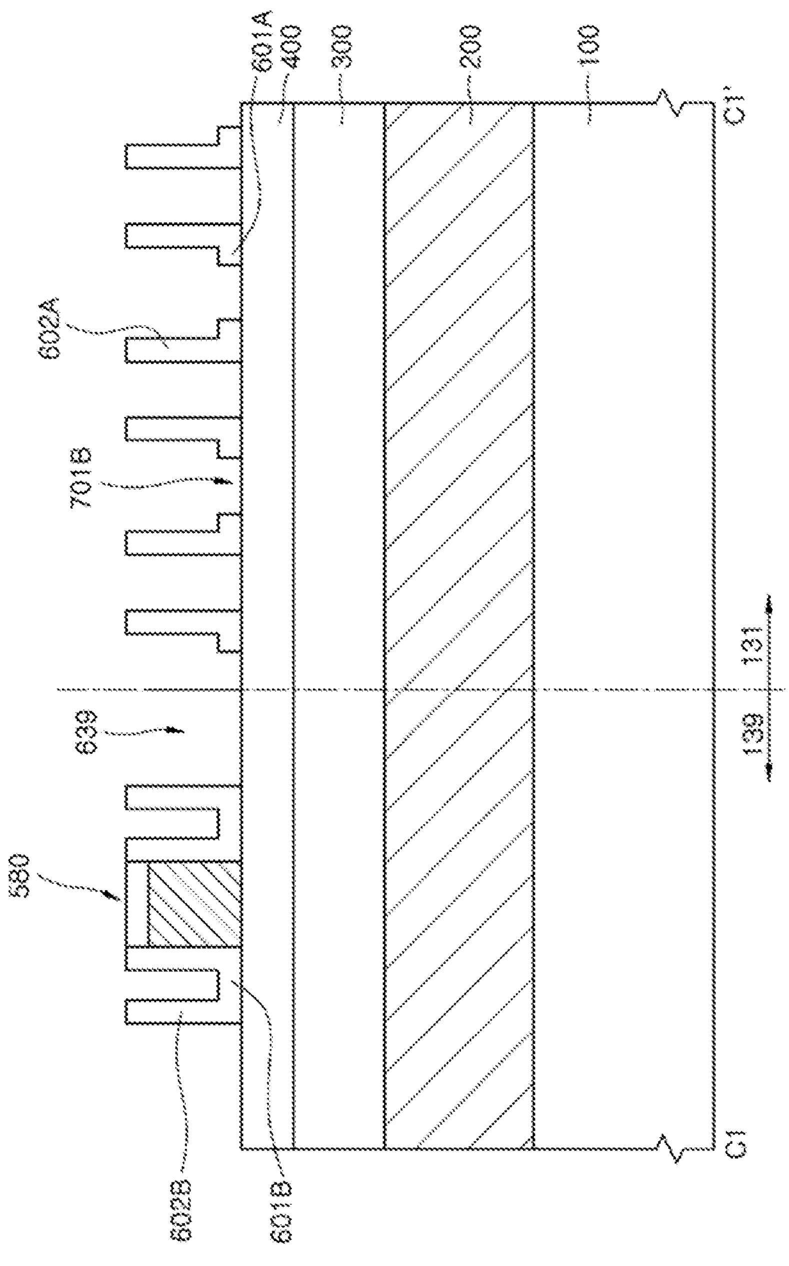
400
300
200
100
C1'
602A
633
810
639
131
139
580
848
848A
602B
601B
C1

FIG. 15



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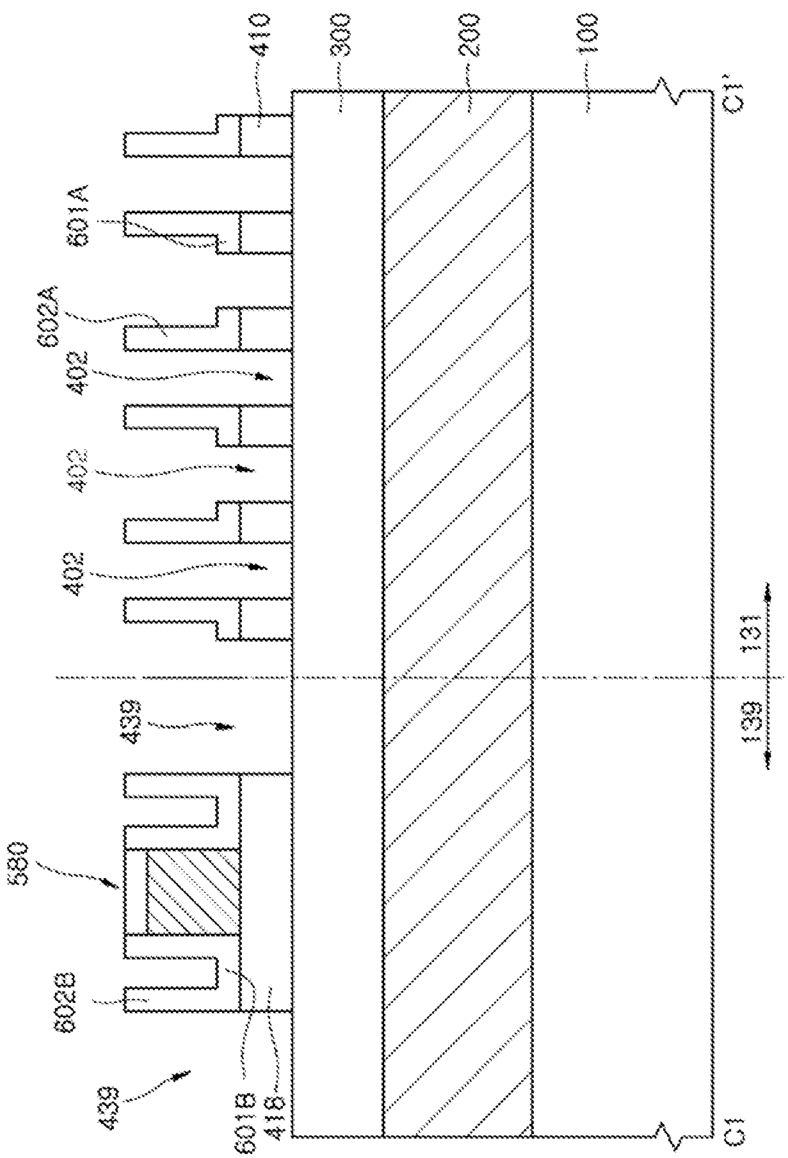
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300
200
100
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601A
602A
402
402
402
439
131
139
580
602B
601B
418
439
C1

FIG. 17

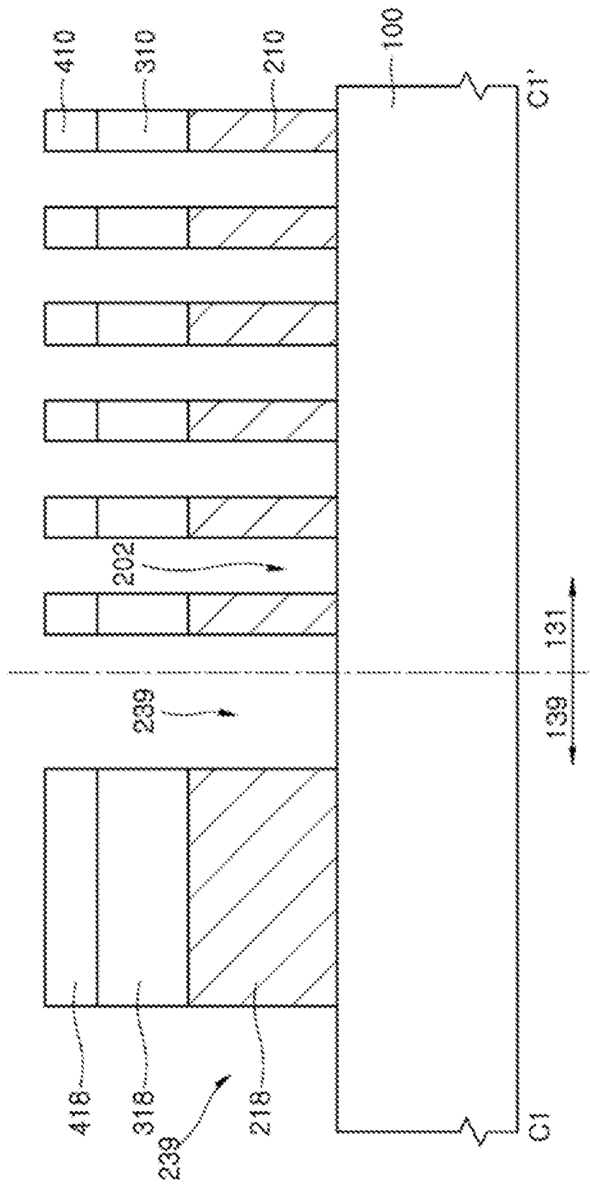


FIG. 18

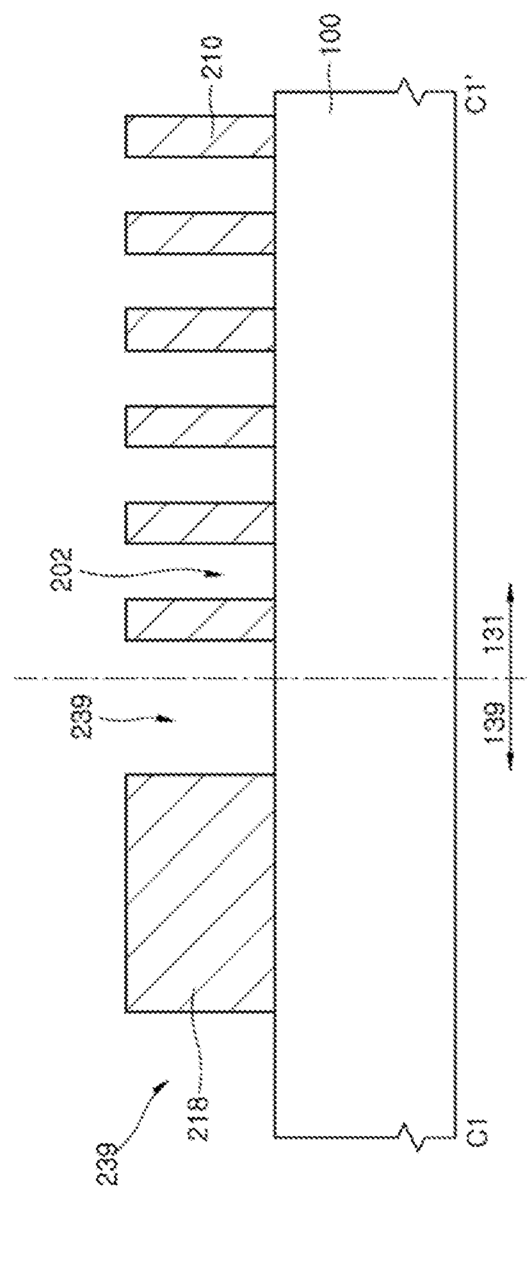


FIG. 19

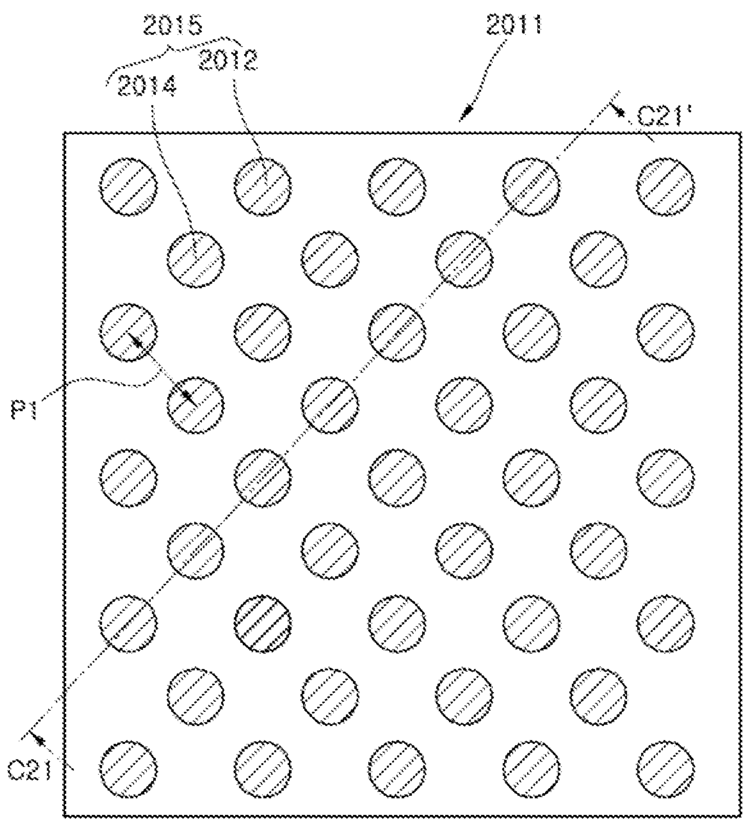
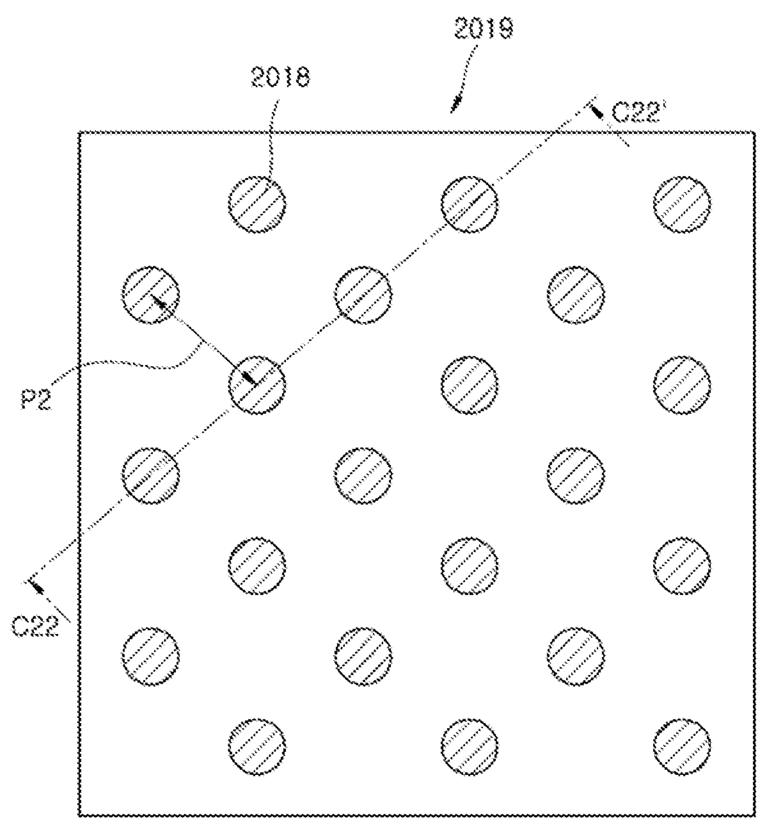


FIG. 20



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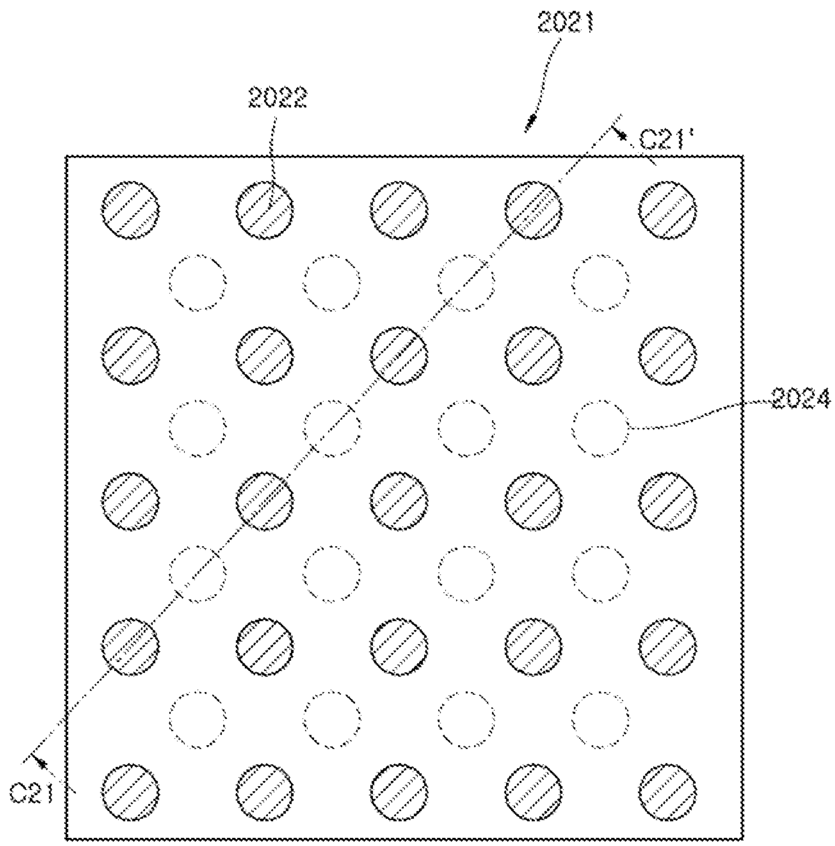
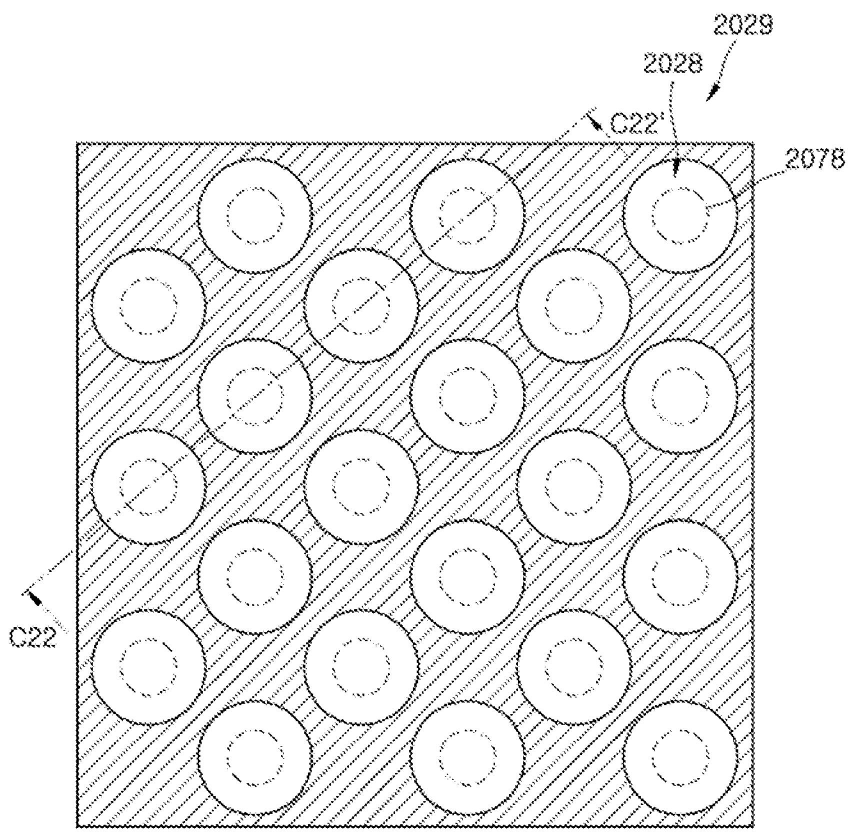


FIG. 22



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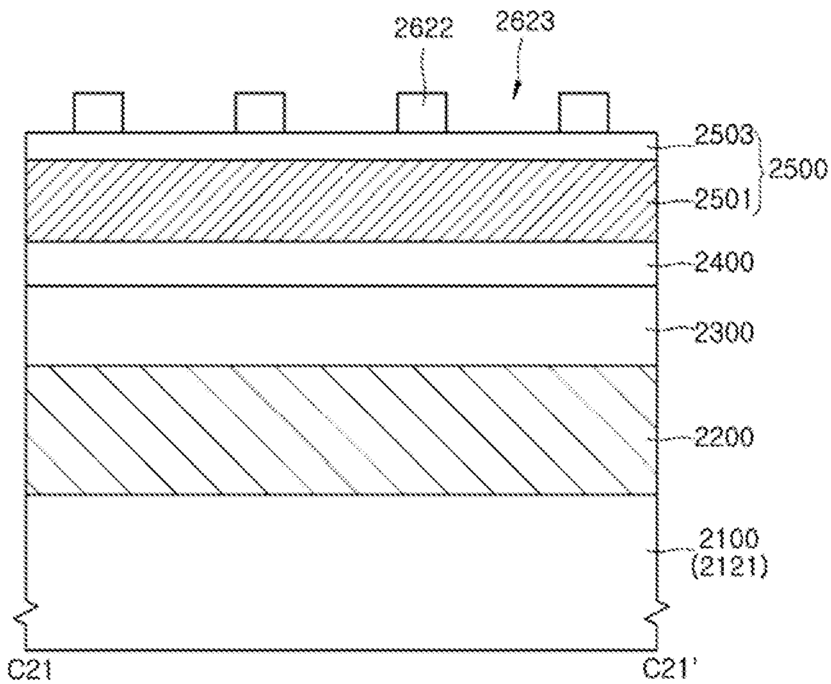


FIG. 24

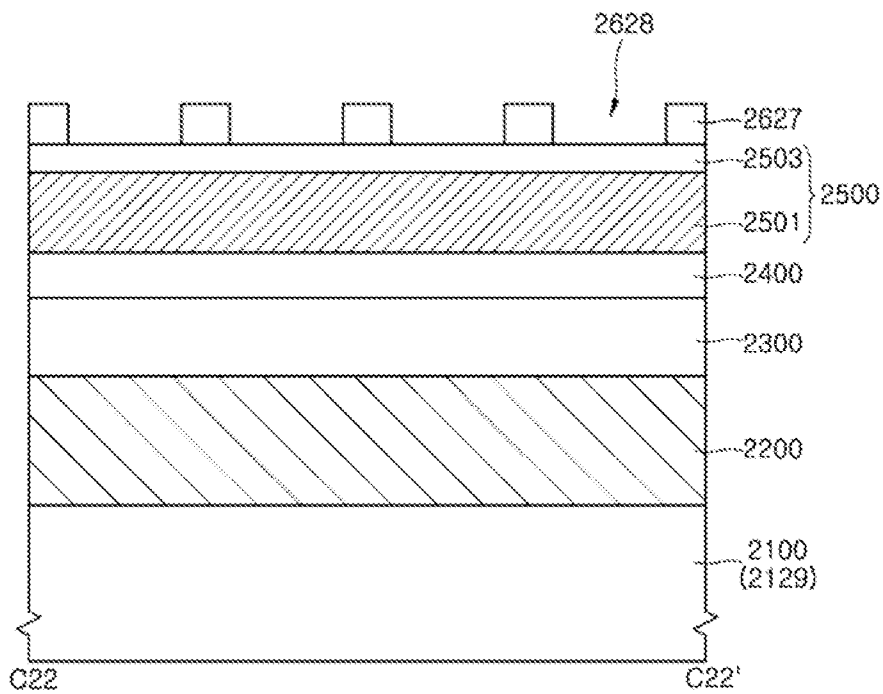


FIG. 25

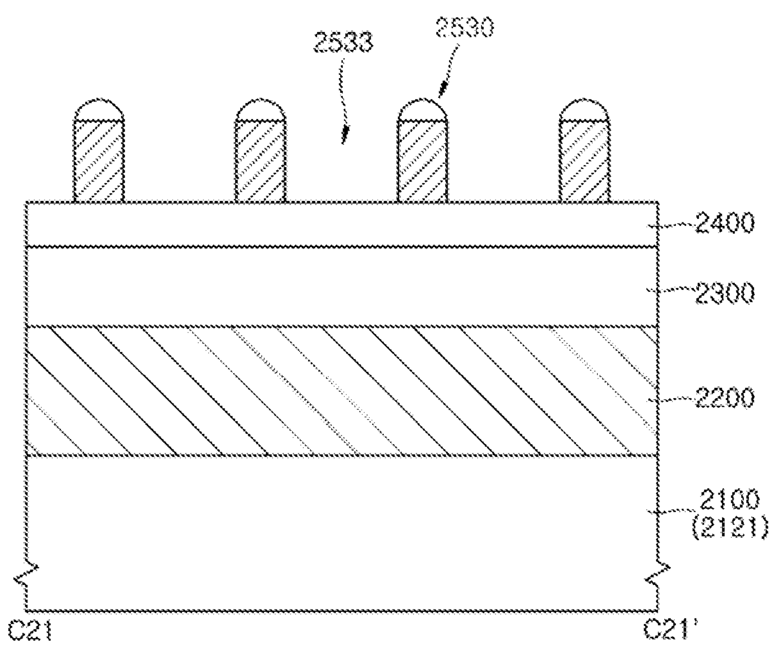
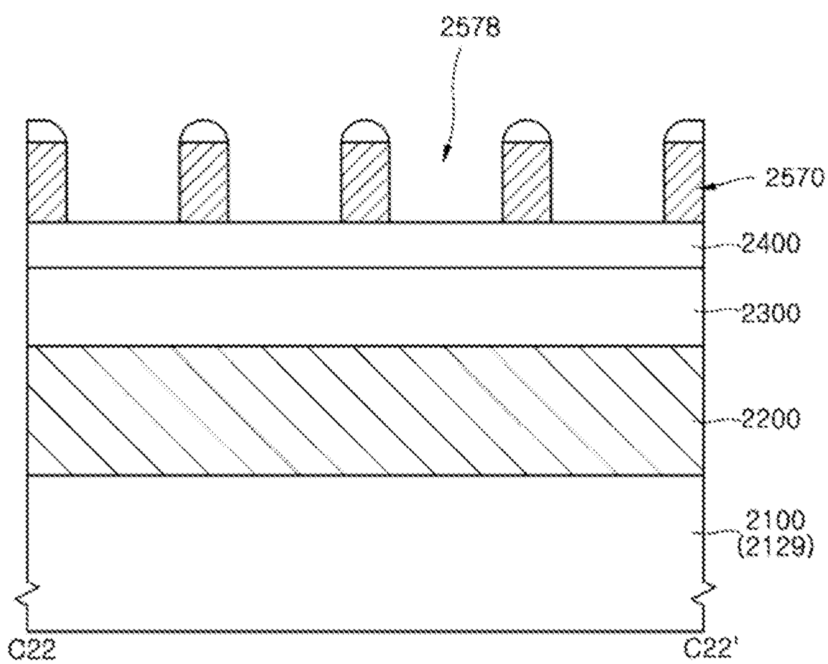


FIG. 26



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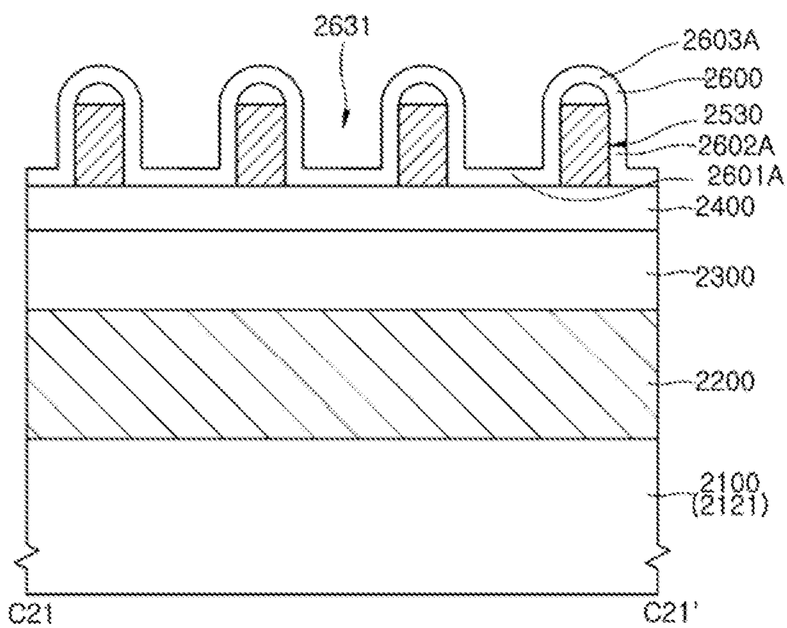

2631
2603A
2600
2530
2602A
2601A
2400
2300
2200
2100
(2121)
C21
C21'

FIG. 28

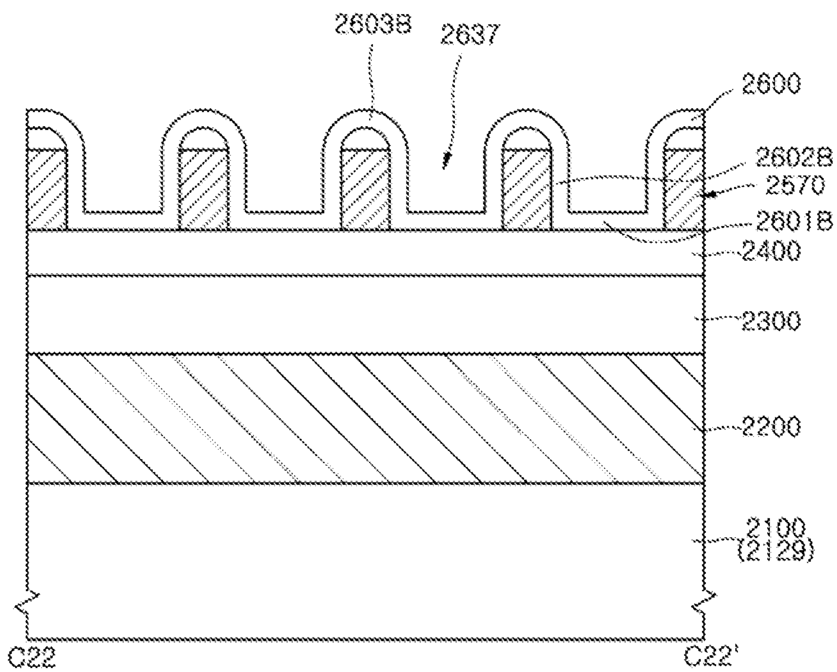
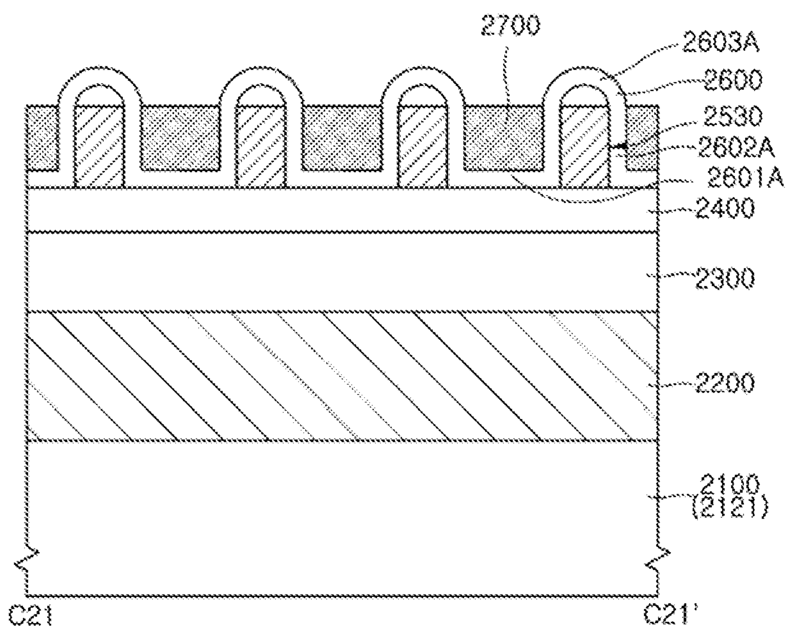

2603B
2637
2600
2602B
2570
2601B
2400
2300
2200
2100
(2129)
C22
C22'

FIG. 29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2601A
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2300
2200
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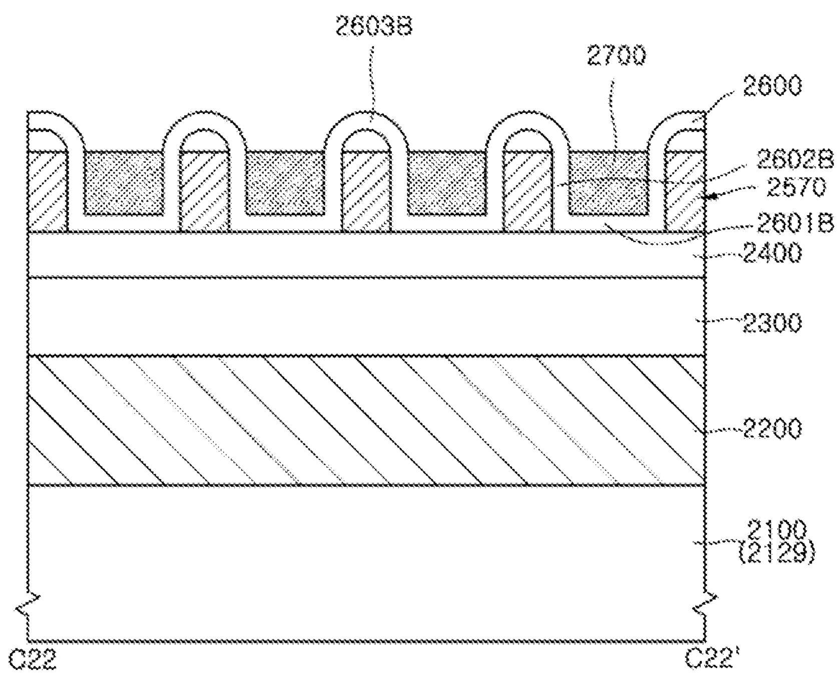
(2121)
C21
C21'

FIG. 30


2603B
2700
2600
2602B
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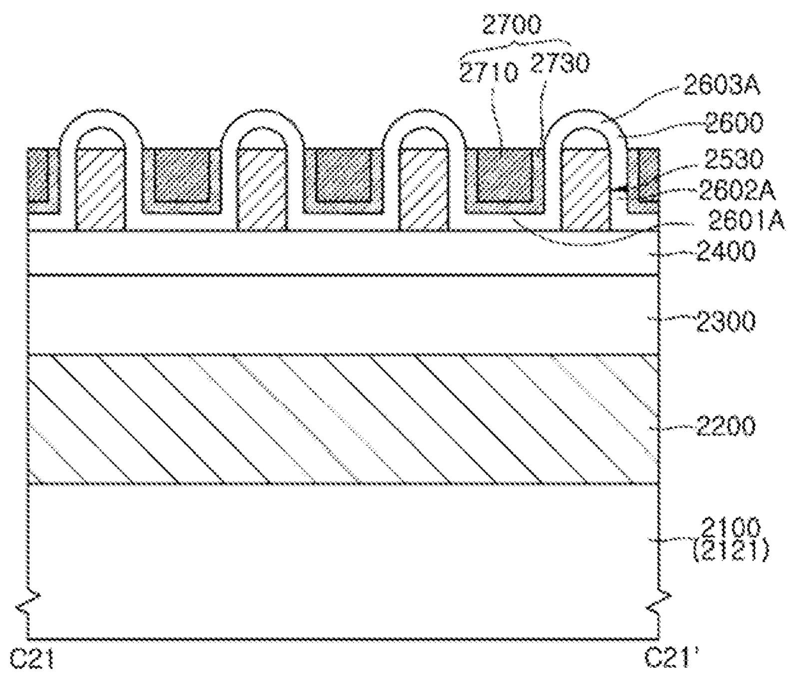
2601B
2400
2300
2200
2100
(2129)
C22
C22'

FIG. 31


2700
2710
2730
2603A
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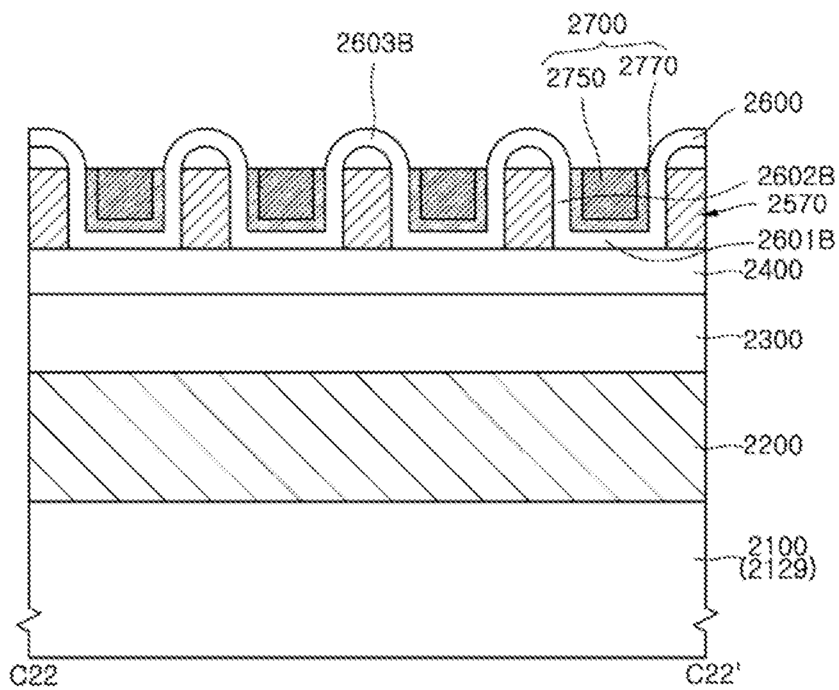
2530
2602A
2601A
2400
2300
2200
2100
(2121)
C21
C21'

FIG. 32


2700
2603B
2750
2770
2600
2602B
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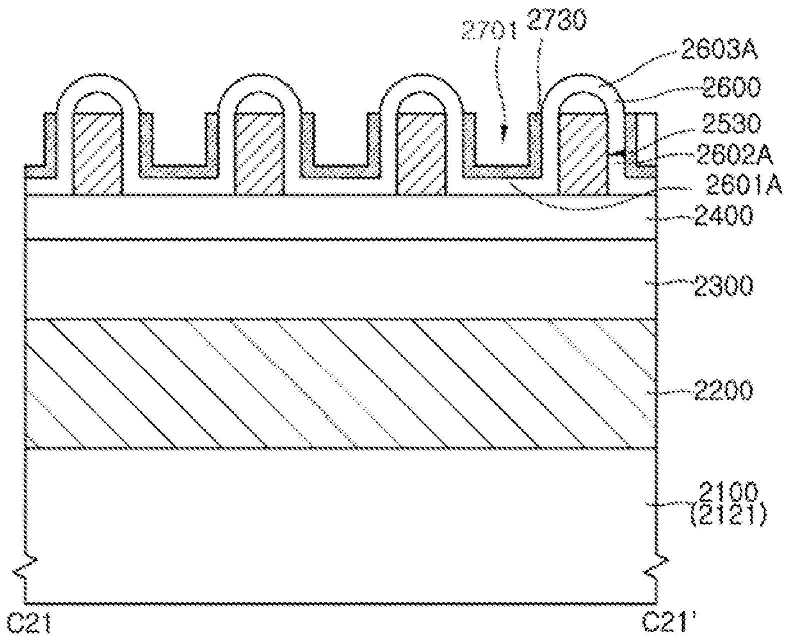
2601B
2400
2300
2200
2100
(2129)
C22
C22'

FIG. 33


2701
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2603A
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2530
2602A
2601A
2400
2300
2200
2100
(2121)
C21
C21'

FIG. 34

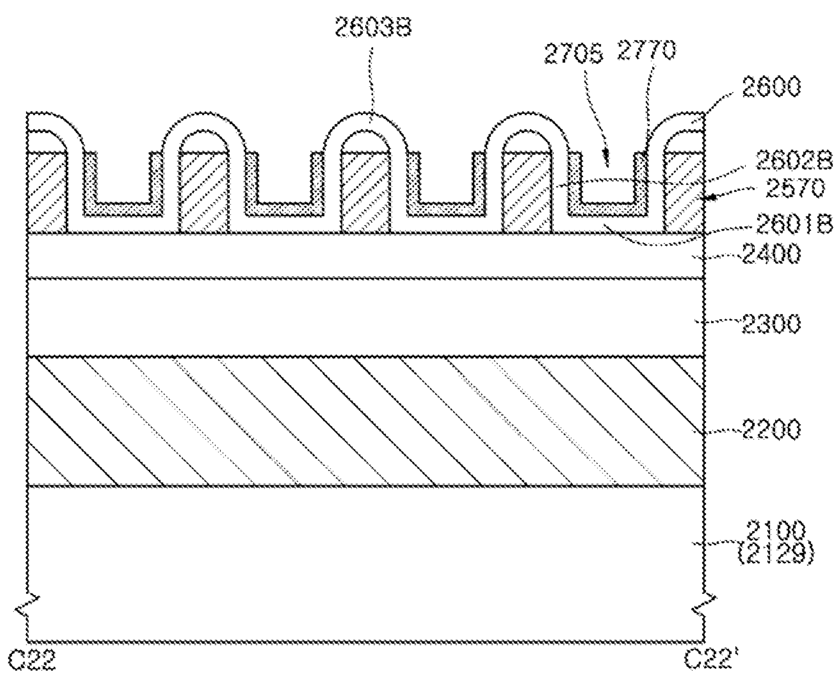
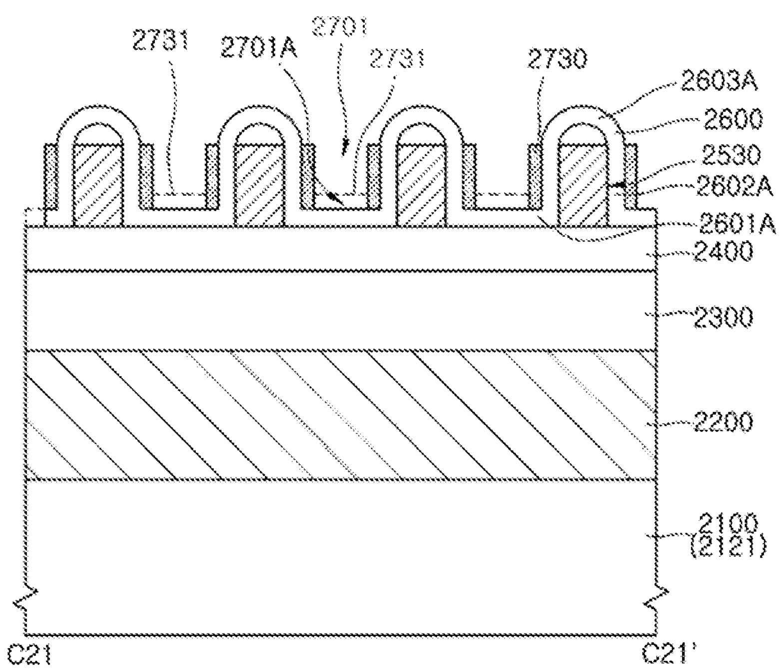

2603B
2705
2770
2600
2602B
2570
2601B
2400
2300
2200
2100
(2129)
C22
C22'

FIG. 35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2602A
2601A
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2300
2200
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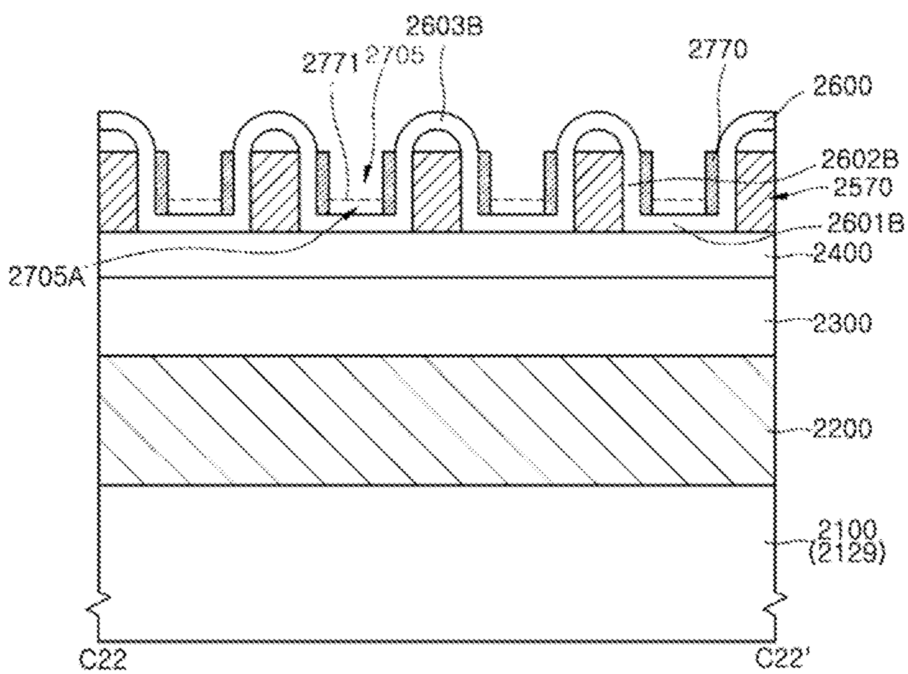
(2121)
C21
C21'

FIG. 36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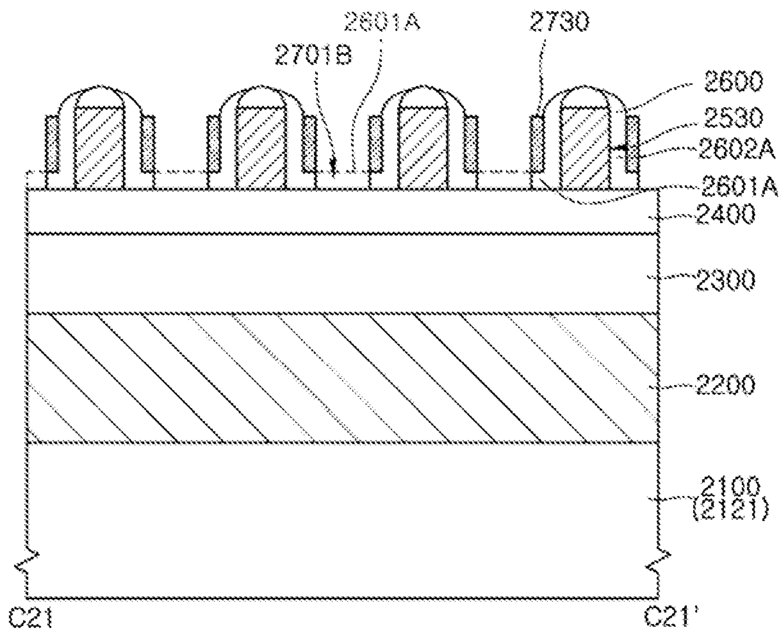
2300
2200
2100
(2129)
C22
C22'

FIG. 37


2601A
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2701B
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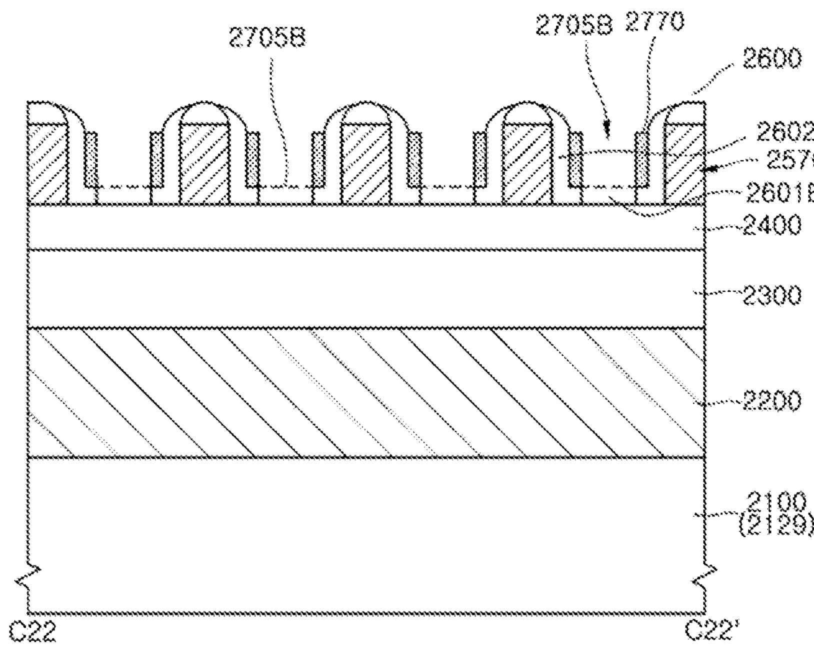
2530
2602A
2601A
2400
2300
2200
2100
(2121)
C21
C21'

FIG. 38



2705B
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2602B
2570
2601B
2400
2300
2200
2100
(2129)
C22
C22'

FIG. 39

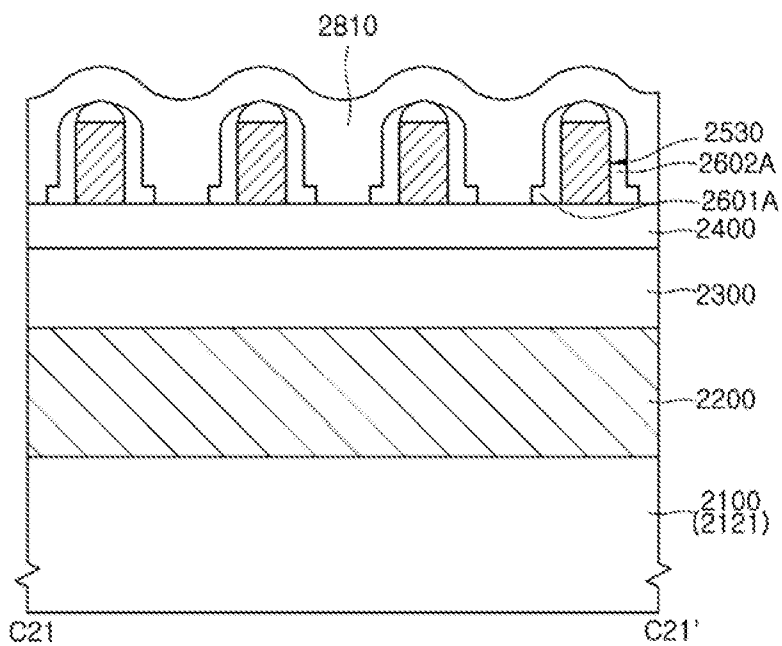
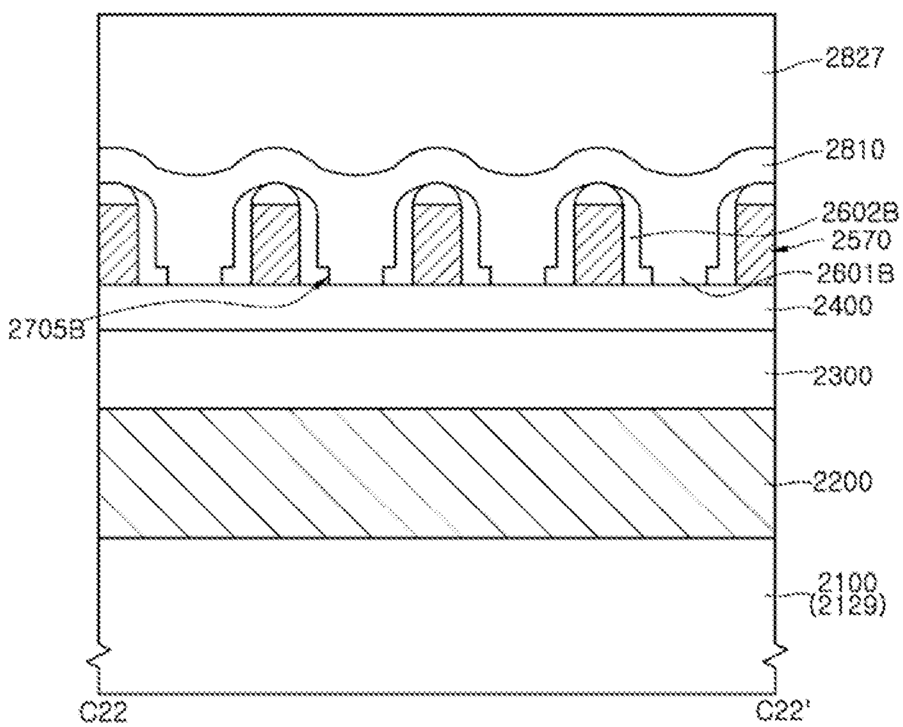


FIG. 40


2827
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2300
2200
2100
(2129)
C22
C22'

FIG. 41

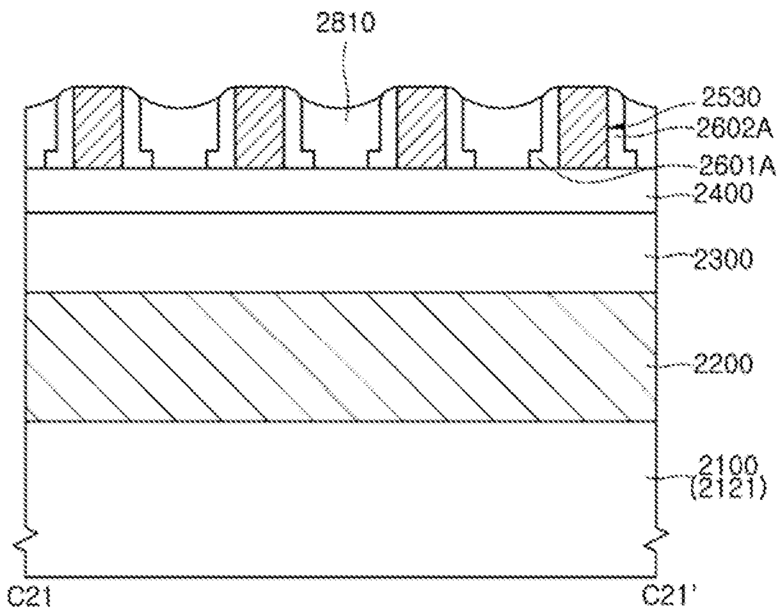
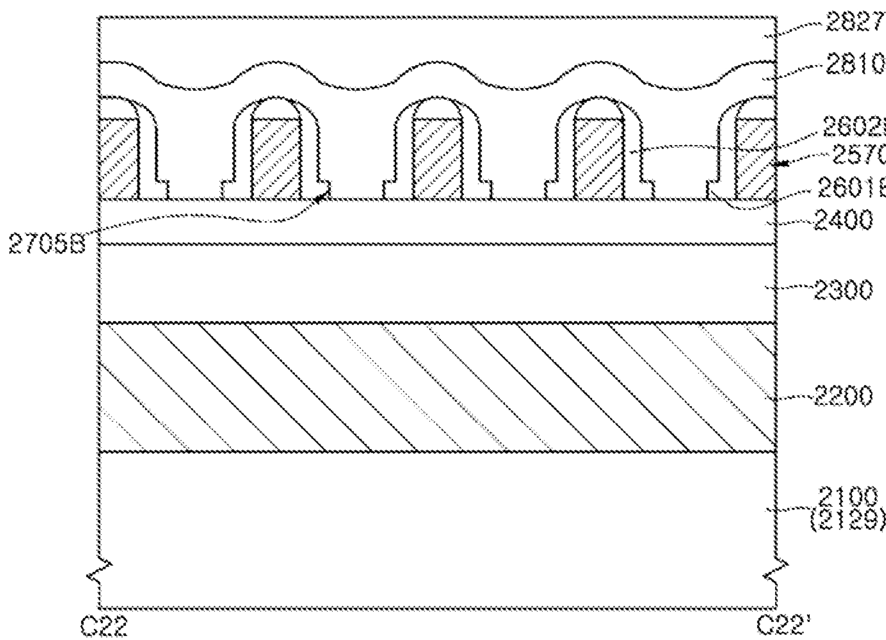


FIG. 42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2200
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(2129)
C22
C22'

FIG. 43

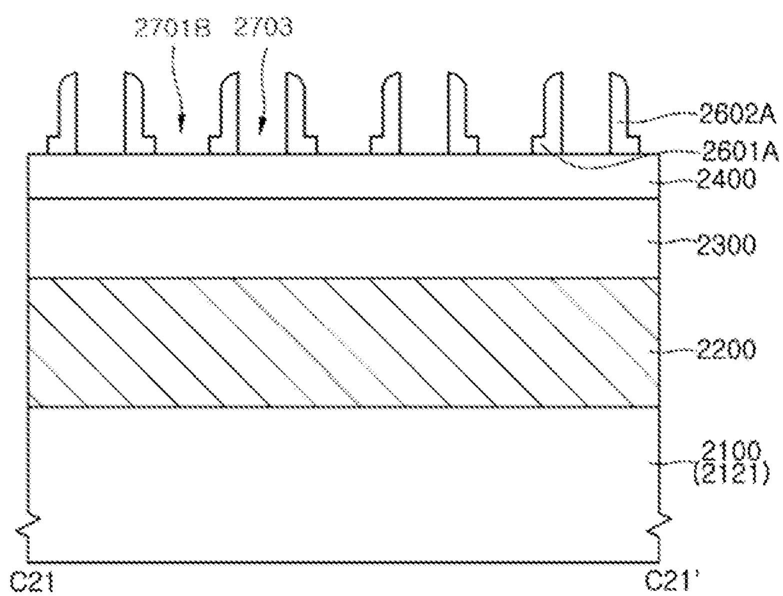


FIG. 44

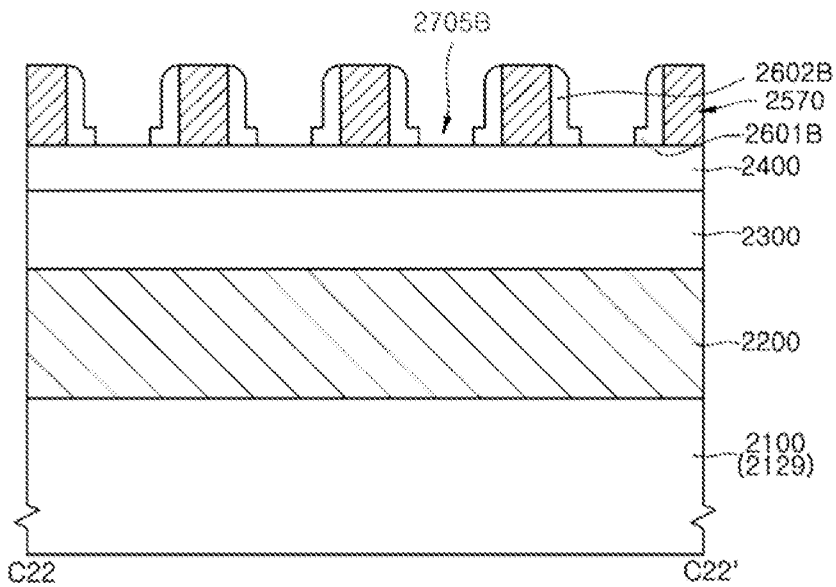


FIG. 45

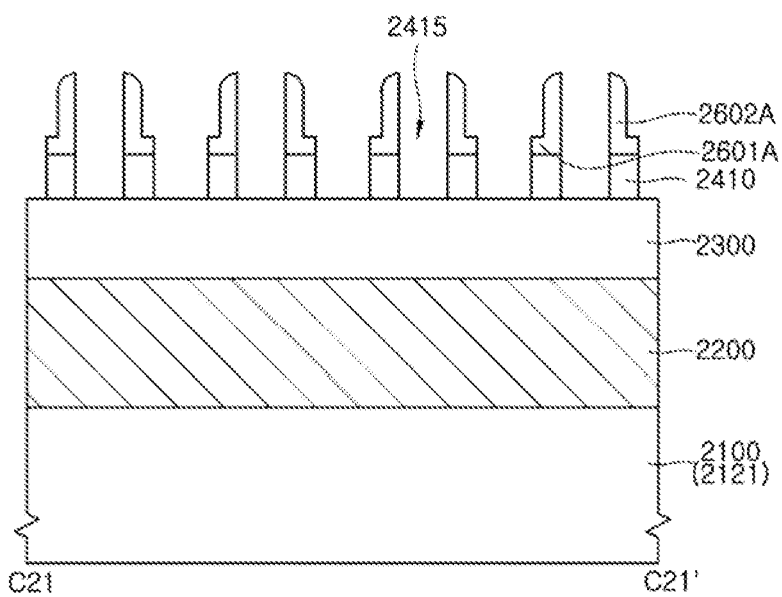


FIG. 46

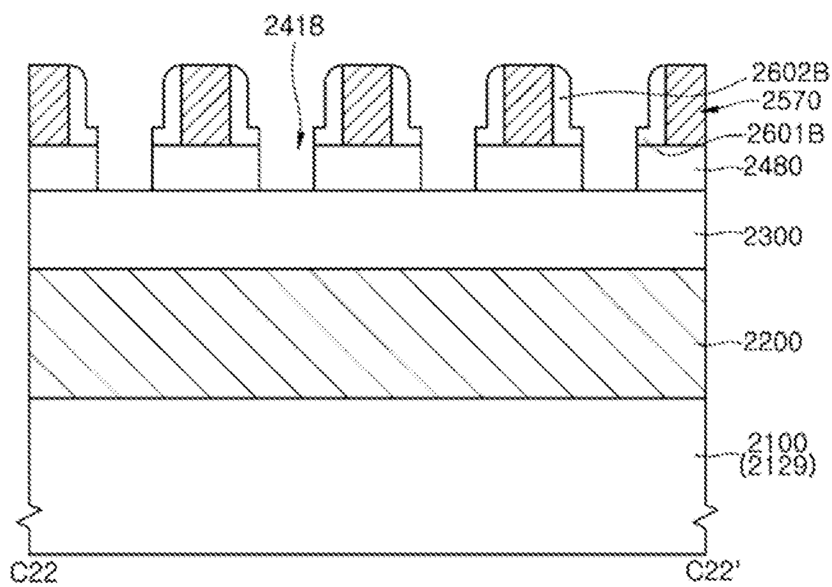


FIG. 47

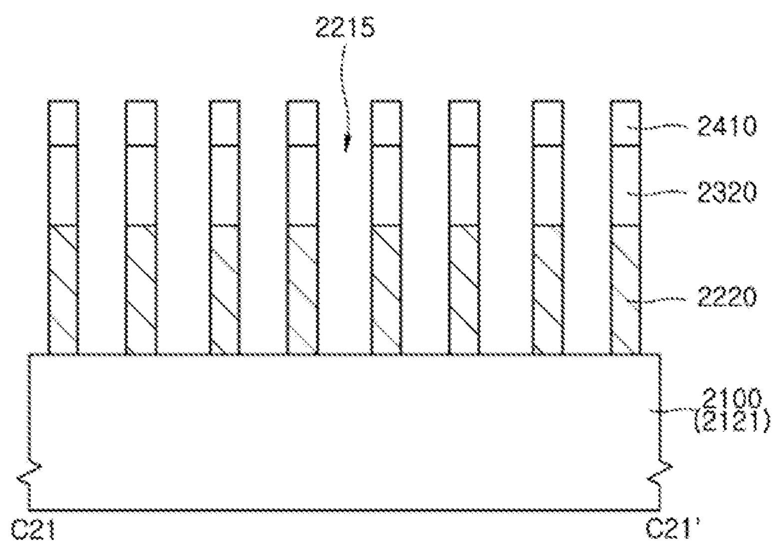


FIG. 48

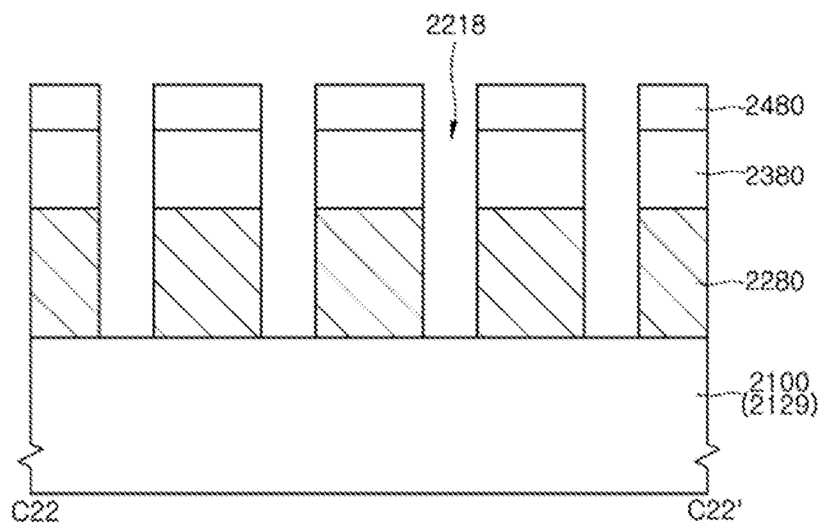


FIG. 49

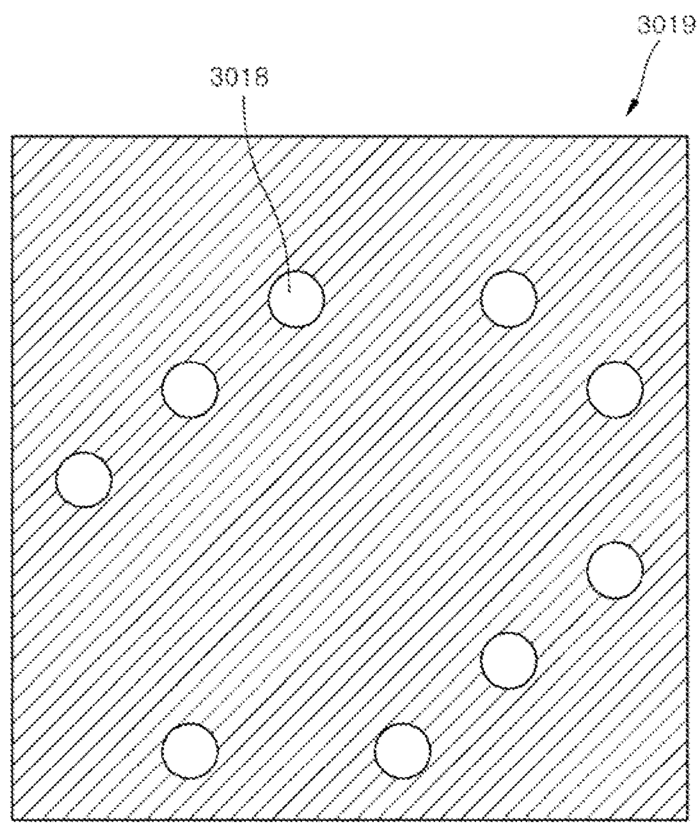


FIG. 50

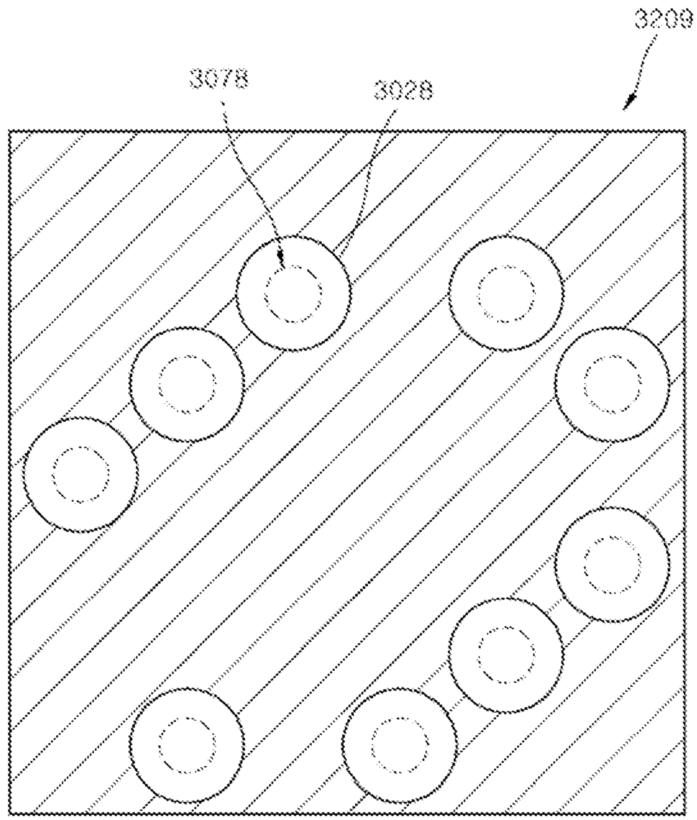


FIG. 51

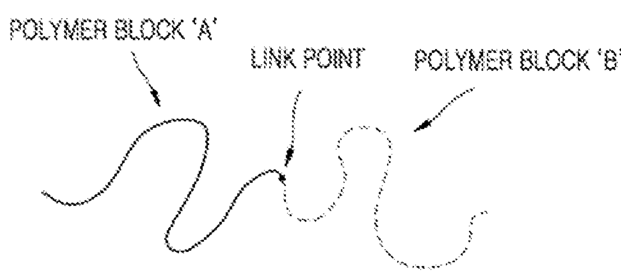


FIG. 52

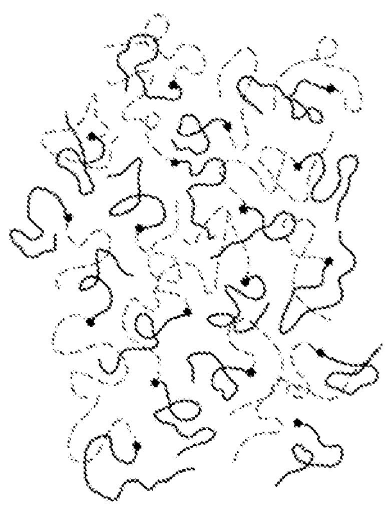
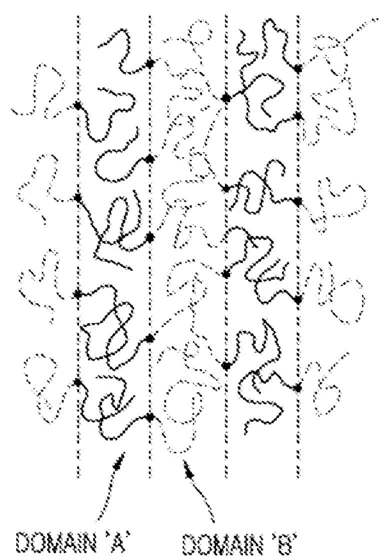


FIG. 53



METHODS OF FORMING DIFFERENT SIZED PATTERNS

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority under 35 U.S.C 119(a) to Korean Application No. 10-2015-0048672, filed on Apr. 6, 2015, which is herein incorporated by reference in its entirety as set forth in full.

BACKGROUND

1. Technical Field

Various embodiments of the present disclosure relate to semiconductor technologies and, more particularly, to methods of forming patterns having different critical dimensions (CDs).

2. Related Art

To increase integration density of semiconductor devices comprised of integrated circuits, it may be necessary to reduce an area occupied by a unit cell of the semiconductor devices and to increase the number of discrete devices such as transistors, resistors, capacitors or the like, integrated in a limited area of a semiconductor substrate. Various techniques have been attempted to realize fine pattern structures having a nano-scale critical dimension (CD), that is, a size ranging from a few nanometers to several tens of nanometers.

It is difficult to form nano-scale fine patterns of the semiconductor devices only with a photolithography process. Image resolution limits of lithography apparatuses for the photolithography process may be caused by the nature of optical systems for the photolithography process and wavelengths of lights generated from light sources of the optical systems. Methods of forming the fine patterns through a self-assembly of polymer molecules may be considered as a candidate for overcoming the image resolution limits. However, it is difficult to merely apply a direct self-assembly (DSA) of polymer molecules to methods of forming a plurality of patterns having different pitches for example, different widths or different spaces. Accordingly, it is necessary to further develop the methods of forming fine patterns using DSA of the polymer molecules to overcome the limitations of DSA technology.

SUMMARY

Various embodiments are directed to methods of forming different sized patterns.

According to an embodiment, there is provided a method of forming patterns. The method may include: forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer; forming a separation wall layer including first separation wall portions surrounding sidewalls of the pillars, and forming second separation wall portions covering sidewalls of the first opening trench portion; forming a block copolymer layer on the separation wall layer; forming first domains in gaps between the pillars, and forming second domains surrounding and separating the first domains by annealing the block copolymer layer; forming second openings by selectively removing the first domains; forming third openings between the second openings, and forming a fourth opening adjacent to the first isolated pattern by selectively removing the pillars and the template portion; and forming fifth openings, which extend

from the second and third openings and penetrate the underlying layer, and forming a sixth opening, which extends from the fourth opening and penetrates the underlying layer.

According to another embodiment, there is provided a method of forming patterns. The method may include: forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer; forming a separation wall layer that covers the pillars, the first isolated pattern and the template portion; forming a block copolymer layer that fills gaps between the pillars and fills a gap between the first isolated pattern and the template portion; forming first domains in the gaps between the pillars, forming second domains surrounding and separating the first domains, forming a third domain in the first opening trench portion, and forming a fourth domain surrounding the third domain, by annealing the block copolymer layer, wherein the third domain is shallower than the first domains and a bottom portion of the fourth domain is thicker than bottom portions of the second domains; forming second openings by removing the first domains, and forming a seventh opening by removing the third domain; forming first extensions of the second openings, which penetrate the bottom portions of the second domains, and an extension of the seventh opening in the fourth domain without penetration of the bottom portion of the fourth domain, by etching the second and fourth domains; forming second extensions of the second openings, and exposing top surfaces of the pillars, a top surface of the first isolated pattern and a top surface of the template portion, by selectively removing portions of the separation wall layer exposed by the first extensions of the second openings; forming third openings by selectively removing the pillars, and forming a fourth opening by selectively removing the template portion; and forming fifth openings that penetrate the underlying layer and extend from the second and third openings, and forming a sixth opening that penetrates the underlying layer and extends from the fourth opening.

According to another embodiment, there is provided a method of forming patterns. The method may include: forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer; forming a separation wall layer that covers the pillars, the first isolated pattern and the template portion; forming a block copolymer layer that fills gaps between the pillars and fills a gap between the first isolated pattern and the template portion; forming first domains in the gaps between the pillars, forming second domains surrounding and separating the first domains, forming a third domain in the first opening trench portion, and forming a fourth domain surrounding the third domain, by annealing the block copolymer layer, wherein the third domain is shallower than the first domains and a bottom portion of the fourth domain is thicker than bottom portions of the second domains; forming second openings by removing the first domains, and forming a seventh opening by removing the third domain; forming first extensions of the second openings which penetrate the bottom portions of the second domains, and an extension of the seventh opening in the fourth domain without penetration of the bottom portion of the fourth domain, by etching the second and fourth domains; forming second extensions of the second openings, and exposing top surfaces of the pillars, a top surface of the first isolated pattern and a top surface of the template portion, by selectively removing portions of the separation wall layer exposed by the first extensions of the second

openings; forming a blocking pattern that covers the first isolated pattern and a portion of the template portion adjacent to the first isolated pattern; forming third openings by selectively removing the pillars using the blocking pattern as an etch mask, and forming a fourth opening by selectively removing the template portion; and forming fifth openings that penetrate the underlying layer and extend from the second and third openings, and forming a sixth opening that penetrates the underlying layer and extends from the fourth opening.

According to another embodiment, there is provided a method of forming patterns. The method may include: forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer; forming a separation wall layer including separation wall portions that cover sidewalls of the pillars and sidewalls of the first openings; forming a block copolymer layer on the separation wall layer; forming first domains in gaps between the pillars, forming second domains surrounding and separating the first domains, forming third domains in the first openings, and forming fourth domains surrounding the third domains, by annealing the block copolymer layer; forming second openings in the gaps between the pillars, and forming third openings in the first openings, by selectively removing the first domains and the third domains; forming fourth openings by selectively removing the pillars; and forming fifth openings that penetrate the underlying layer and extend from the second and fourth openings, and forming sixth openings that penetrate the underlying layer and extend from the third openings.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present disclosure will become more apparent in view of the attached drawings and accompanying detailed description, in which:

FIGS. **1** to **3** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to an embodiment;

FIG. **4** is a plan view illustrating a layout of a blocking pattern used in a method of forming patterns according to an embodiment;

FIGS. **5** to **18** are cross-sectional views illustrating a method of forming patterns according to an embodiment;

FIGS. **19** to **22** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to another embodiment;

FIGS. **23** to **48** are cross-sectional views illustrating a method of forming patterns according to another embodiment;

FIGS. **49** and **50** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to still another embodiment; and

FIGS. **51** to **53** are schematic views illustrating phase separations of block copolymer (BCP) layers used in exemplary embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

It will be understood that although the terms first, second, third etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another element. Thus, a first element in exemplary embodiments could be termed a second element in other embodiments without departing from the teachings of the present disclosure.

It will also be understood that when an element is referred to as being located "under", "beneath," "below", "lower," "on", "over", "above," "upper", "side" or "aside" another element, it can be directly contact the other element, or at least one intervening element may also be present therebetween. Accordingly, the terms such as "under", "beneath," "below", "lower,", "on", "over", "above," "upper", "side", "aside" and the like which are used herein are for the purpose of describing particular embodiments only and are not intended to limit the scope of the present disclosure. Other words used to describe the relationship between elements or layers should be interpreted in a like fashion for example, "between" versus "directly between" or "adjacent" versus "directly adjacent".

In the following embodiments, the term "dense patterns" may be used to describe patterns having a relatively small pitch size and a relatively short distance therebetween, and the term "isolated patterns" may be used to describe patterns having a relatively large pitch size and a relatively long distance therebetween. In addition, the term "regularly arrayed patterns" may be used to describe patterns arrayed to have a uniform pitch size and substantially the same distance therebetween, and the term "irregularly arrayed patterns" may be used to describe patterns arrayed to have non-uniform pitch sizes or different distances therebetween. The term "irregularly arrayed patterns" may also be used to describe patterns randomly arrayed without any regularity.

Exemplary embodiments of the present disclosure may provide methods of forming fine patterns through a phase separation of a block copolymer (BCP) layer so that the patterns have a line width less than a resolution limit of exposure apparatuses. For example, exemplary embodiments of the present disclosure may provide methods of forming an array of contact holes or an array of cutting holes for cutting line-shaped patterns through a direct self-assembly (DSA) technique of the BCP layer. Specific polymer blocks included in the BCP layer may be ordered and phase-separated from a matrix material to form domain portions under a specific condition, and the phase-separated domain portions may be selectively removed to form spaces or patterns having a nano-scaled feature size. The nano-scaled feature size may range from a few nanometers to several tens of nanometers.

A self-assembled structure of the BCP layer may have a cylindrical shape or a lamellar shape according to a volume ratio of two or more distinct polymer blocks included in the BCP layer, an annealing temperature for the phase separation of the BCP layer, a molecule size of the polymer blocks included in the BCP layer, and a molecular weight of the polymer blocks included in the BCP layer. That is, the phase-separated domain portions of the polymer blocks may have a cylindrical shape or a lamellar shape. When the self-assembled structure of the BCP layer has a cylindrical shape, the BCP layer may be used to form a hole array pattern. When the self-assembled structure of the BCP layer has a lamellar shape, the BCP layer may be used to form a line and space pattern.

Various embodiments of the present disclosure may be applied to fabrication of highly integrated semiconductor devices, for example, dynamic random access memory (DRAM) devices, phase changeable random access memory (PcRAM) devices or resistive random access memory (ReRAM) devices. In addition, the following embodiments may be applied to fabrication of memory devices such as static random access memory (SRAM) devices, flash memory devices, magnetic random access memory (MRAM) devices or ferroelectric random access memory (FeRAM) devices. The following embodiments may also be applied to fabrication of logic devices, such as control devices, central processing units (CPU) or arithmetic logic units (ALU).

FIGS. **1** to **3** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to an embodiment.

Referring to FIG. **1**, a layout **10** of a target feature may include a layout **11** having an array of first target features **12** that are to be transferred onto a substrate to form fifth openings, and may include a layout **19** having a second target feature **18** that is to be transferred onto the substrate to form a second isolated pattern. The layout **11** of the first target features **12** and the layout **19** of the second target feature **18** may be located at different regions. For example, the layout **11** and the layout **19** may be adjacent to each other. The first target features **12** may be disposed in a dense pattern region such as a cell region, and the second target feature **18** may be disposed in an isolated pattern region such as a peripheral region. The second target feature **18** may have a line shape or a polygonal shape.

In the layout **11**, the first target features **12** may include pillar features **13** for portions of guide patterns, and first domain features **14** between the pillar features **13**. The first domain features **14** may be surrounded by four adjacent pillar features **13** during phase separation of the BCP material. Accordingly, the pillar features **13** may be separated from the first domain features **14** according to the phase separation of the BCP material.

Referring to FIGS. **1** and **2**, a layout **20** may include a layout **21** having pillar features **23** and a layout **29** having a first isolated pattern **28** and a first opening trench portion **27**. The layout **21** having the pillar features **23** may be obtained by separating the first domain features **14** from the layout **11** of the first target features **12**. The layout of the first isolated pattern **28** may be obtained by resizing the second target feature **18** corresponding to the second isolated pattern. For example, the layout of the first isolated pattern **28** may be obtained by two-dimensionally shrinking the second target feature **18** by "R1" as shown in FIG. **2**. In such a case, the layout of the first opening trench portion **27** may be obtained by removing the layout of the first isolated pattern **28** from the second target feature **18**.

Referring to FIG. **3**, a layout **30** of guide patterns may include pillar features **33** arrayed in a region **31**, a template portion **39** exposing the region **31**, and a first isolated pattern **38** disposed in the template portion **39** spaced apart from the template portion **39**. The pillar features **33** may correspond to the pillar features **23** of FIG. **2**, and the first isolated pattern **38** may correspond to the first isolated pattern **28** of FIG. **2**. A region **37** between the template portion **39** and the first isolated pattern **38** may correspond to a first opening trench portion **27** of FIG. **2**. That is, the first isolated pattern **38** may be surrounded by the first opening trench portion **37** in the template portion **39**.

FIG. **4** is a plan view illustrating a layout **40** of a blocking pattern **48**.

Referring to FIGS. **1** to **4**, the layout **40** may include the blocking pattern **48** that is transferred onto the first isolated pattern **38** to form a mask pattern covering the first isolated pattern **38**. The mask pattern formed by the blocking pattern **48** may remain to protect the first isolated pattern **38** while the template portion **39** is selectively removed. Thus, the first isolated pattern **38** may still remain due to the presence of the mask pattern formed by the blocking pattern **48** during removal of the template portion **39**. The blocking pattern **48** may be obtained by two-dimensionally enlarging the first isolated pattern **38**. For example, the blocking pattern **48** may have a layout of the second isolated pattern **18**. In exemplary embodiments, the blocking pattern **48** may be formed by two-dimensionally enlarging the second isolated pattern **18** to overlap with a portion of the template portion **39** adjacent to the second isolated pattern **18**.

FIGS. **5** to **18** are cross-sectional views taken along a line **C1-C1'** of FIGS. **1** to **3** to illustrate a method of forming patterns according to an embodiment.

FIG. **5** illustrates a step of forming mask patterns **633**, **638** and **639** on a guide layer **500**.

Referring to FIGS. **1** to **5**, the mask patterns **633**, **638** and **639** may be formed on the guide layer **500**. The mask patterns **633**, **638** and **639** may serve as etch masks when the guide layer **500** is etched in a subsequent process. The mask patterns **633**, **638** and **639** may include first patterns **633** corresponding to the pillars **33**, a second pattern **638** corresponding to the first isolated pattern **38**, and a third pattern **639** corresponding to the template portion **39**. Thus, a space region **637** between the second pattern **638** and the third pattern **639** may have substantially the same shape as the first opening trench portion **37**. The mask patterns **633**, **638** and **639** may include a photoresist material.

The guide layer **500** may be patterned in a subsequent process to form guide patterns, which are described with reference to FIGS. **1** to **3** and define positions of the domains in the phase-separated BCP layer. The guide layer **500** may be formed on a semiconductor substrate **100**. The semiconductor substrate **100** may include a first region **131** on which the pillars **33** are disposed with high density, and may include a second region **139** on which the second isolated pattern **18** is disposed. The second region **139** may be distinct from and adjacent to the first region **131**. The guide layer **500** may include a spin-on-carbon (SOC) layer **501** disposed on an underlying layer **400**. The SOC layer **501** may have a thickness ranging from about 700 to about 800 angstroms. The guide layer **500** may further include a capping layer **503** disposed on the SOC layer **501**. The capping layer **503** may be formed of a silicon oxynitride (SiON) layer having a thickness of about 300 angstroms.

The underlying layer **400** may be used to pattern a part of or an entire hard mask in a subsequent patterning process. For example, the underlying layer **400** may serve as one of multi-layers in a hard mask system. A second etch target layer **300** may be formed between the underlying layer **400** and the semiconductor substrate **100**. In addition, a first etch target layer **200** may be formed between the second etch target layer **300** and the semiconductor substrate **100**. The first or second etch target layer **200** or **300** may be one of the hard mask system, or may be selectively etched using the hard mask system as an etch mask in a subsequent process.

The first etch target layer **200** may be formed of an interlayer insulation layer including a silicon oxide layer such as a tetra-ethyl-ortho-silicate (TEOS) layer having a thickness of about 2200 angstroms. Alternatively, the first etch target layer **200** may be formed of a conductive layer such as a doped polysilicon layer. The second etch target layer **300** may be formed by depositing an amorphous SOC layer having a thickness ranging from about 730 to about 1000 angstroms on the first etch target layer **200**. The underlying layer **400** may be formed on the second etch target layer **300** and may include a silicon oxynitride (SiON) layer having a thickness ranging from about 300 to about 350 angstroms.

FIG. 6 illustrates a step of forming an array of pillars **530**, a first isolated pattern **580** and a template portion **590**.

Referring to FIG. 6, the guide layer **500** may be etched using the mask patterns **633**, **638** and **639** as etch masks, thereby forming the array of the pillars **530**, the first isolated pattern **580** and the template portion **590**. The array of the pillars **530** may be formed on the first region **131** of the semiconductor substrate **100**, and the first isolated pattern **580** and the template portion **590** may be formed on the second region **139** of the semiconductor substrate **100**. A space region between the first isolated pattern **580** and the template portion **590** may correspond to a first opening trench portion **570**.

The pillars **530** may be arrayed so that four adjacent pillars **530** are positioned to form a rectangular shape. Alternatively, the pillars **530** may be arrayed so that three adjacent pillars **530** are positioned to form a triangular shape. The pillars **530** may be arrayed to have a gap **531** between two adjacent pillars **530** which are disposed on the line C**1**-C**1**'. As illustrated in FIG. 3, a gap between two adjacent pillars **33** which are arrayed on a horizontal line may be narrower than the gap between two adjacent pillars **33** which are arrayed on the diagonal portion of the line C**1**-C**1**'. The pillars **530** may serve as guide patterns that induce self-assembly of the BCP layer which is formed in a subsequent process. The first isolated pattern **580** and the template portion **590** may serve as guide patterns that prevent the self-assembly of the BCP layer on the second region **139**.

FIG. 7 illustrates a step of forming a separation wall layer **600**.

Referring to FIGS. 6 and 7, the separation wall layer **600** may include first separation wall portions **602**A covering sidewalls of the pillars **530**, and second separation wall portions **602**B covering sidewalls of the first opening trench portion **570**. The separation wall layer **600** may include first extensions **601**A extending from the first separation wall portions **602**A to cover portions of the underlying layer **400** exposed by the gaps **531**, and second extensions **603**A extending from the first separation wall portions **602**A to cover top surfaces of the pillars **530**. The separation wall layer **600** may further include third extensions **601**B extending from the second separation wall portions **602**B to cover portions of the underlying layer **400** exposed by the first opening trench portion **570**, and fourth extensions **6038** extending from the second separation wall portions **602**B to cover top surfaces of the first isolated pattern **580** and the template portion **590**.

The separation wall layer **600** may provide recessed regions defined by gaps **631** between the pillars **530**, and a recessed region defined by a gap **637** between the first isolated pattern **580** and the template portion **590**. The separation wall layer **600** may be formed of an insulation layer having an etch selectivity with respect to the pillars **530** and the underlying layer **400**. For example, the separation wall layer **600** may be formed of an ultra-low temperature oxide (ULTO) layer having a thickness of about 200 angstroms.

FIG. 8 illustrates a step of forming the BCP layer **700**.

Referring to FIG. 8, the BCP layer **700** may be formed on the separation wall layer **600** to fill the gaps **631** and **637** which are provided by the pillars **530**, the first isolated pattern **580** and the template portion **590**. The BCP layer **700** may include a polystyrene-poly (meta methyl acrylate) block copolymer (PS-b-PMMA) material or a polystyrene-poly (di methyl siloxane) (PS-PDMS) block copolymer material. When the BCP layer **700** is formed of the PS-b-PMMA material including PS blocks and PMMA blocks, a volume ratio of the PS blocks to the PMMA blocks may be controlled to be within the range from about 7:3 to about 5:5. The volume ratio of the PS blocks to the PMMA blocks or molecular weights of the PS block and the PMMA block may be appropriately controlled according to a process scheme. For example, the PS-b-PMMA material may have a PS block content of about 60 vol. % to about 80 vol. % and a PMMA block content of about 20 vol. % to about 40 vol. %.

FIGS. 51 to 53 are schematic views illustrating the phase separation of the BCP layer **700** for exemplary embodiments. The BCP layer **700** may be a functional polymer material made by combining polymer blocks having two or more distinct structures into a single block copolymer material through a covalent bond, as illustrated in FIG. 51. As illustrated in FIG. 51, the BCP layer **700** may have a chain shape including polymer blocks 'A' and 'B', which are connected to each other by a covalent bond through a link point. Referring to FIG. 52, the BCP layer **700** may be coated to have a homogeneous phase. Referring to FIG. 53, the polymer blocks having distinct structures in the BCP layer **700** may have different miscibility and different solubility from each other due to different chemical structures thereof. That is, the polymer blocks having distinct structures are immiscible with each other at a certain temperature. Thus, the BCP layer **700** may be phase-separated through an annealing process to provide a self-aligned structure. Accordingly, the BCP layer **700** having a homogeneous phase may be phase-separated into a domain 'A' in which polymer blocks 'A' are ordered and a domain 'B' in which polymer blocks 'B' are ordered, through an annealing process. As such, polymer blocks of the BCP layer **700** may be phase-separated or selectively dissolved in a liquid state or in a solid state to form a self-assembled structure.

A nano-scale structure having a specific shape through the self-assembly of the BCP layer **700** may be affected by a physical property and/or a chemical property of the polymer blocks of the BCP layer **700**. When a BCP layer including two distinct polymer blocks is self-assembled on the substrate, the self-assembled structure of the BCP layer may have a three dimensional cubic shape, a three dimensional double helix shape, a two dimensional hexagonal packed column shape, a two dimensional lamella shape and so forth according to a volume ratio of the polymer blocks included in the BCP layer, an annealing temperature for phase separation of the BCP layer, and a molecule size of the polymer blocks included in the BCP layer.

In exemplary embodiments, the BCP layer **700** may be formed of polybutadiene-polybutylmethacrylate block copolymer, polybutadiene-polydimethylsiloxane block copolymer, polybutadiene-polymethylmethacrylate block copolymer, polybutadienepolyvinylpyridine block copolymer, polybutylacrylate-polymethylmethacrylate block copolymer, polybutylacrylate-polyvinylpyridine block copolymer, polyisoprene-polyvinylpyridine block copolymer, polyisoprene-polymethylmethacrylate block copolymer, polyhexylacrylatepolyvinylpyridine block copolymer, polyisobutylene-polybutylmethacrylate block copolymer, polyisobutylene-polymethylmethacrylate block copolymer, polyisobutylene-polybutylmethacrylate block copolymer, polyisobutylenepolydimethylsiloxane block copolymer, polybutylmethacrylatepolybutylacrylate block copolymer, polyethylethylene-polymethylmethacrylate block copolymer, polystyrene-polybutylmethacrylate block copolymer, polystyrene-polybutadiene block copolymer, polystyrene-polyisoprene block copolymer, polystyrene-polydimethylsiloxane block copolymer, polystyrene-polyvinylpyridine block copolymer, polyethylethylene-polyvinylpyridine block copolymer, polyethylene-polyvinylpyridine block copolymer, polyvinylpyridinepolymethylmethacrylate block copolymer, polyethyleneoxide-polyisoprene block copolymer, polyethyleneoxide-polybutadiene block copolymer, polyethyleneoxide-polystyrene block copolymer, polyethyleneoxidepolymethylmethacrylate block copolymer, polyethyleneoxide-polydimethylsiloxane block copolymer, polystyrene-polyethyleneoxide block copolymer and so forth.

FIG. **9** illustrates a step of phase-separating the BCP layer **700**.

Referring to FIGS. **6** to **9**, the BCP layer **700** may be phase-separated through an annealing process into first domains **710** respectively located at central portions of the gaps **631** between the pillars **530** arrayed on the line C**1**-C**1**', and a second domain **730** disposed between the pillars **530** to surround the first domains **710** and to isolate the first domains **710** from each other. The first domains **710** may fill recessed regions provided by the second domain **730**. Thus, the first domains **710** may have post shapes and may be surrounded by the second domain **730**.

While the BCP layer **700** is phase-separated through an annealing process, a portion of the BCP layer **700** filling the gap **637** provided by the separation wall layer **600** on the second region **139** may be phase-separated into a third domain **750** and a fourth domain **770** surrounding the third domain **750** in the gap **637**. In such a case, the third domain **750** may insufficiently expand toward a bottom surface of the gap **637** to have a smaller depth than the first domains **710**. This is due to the gap **637** having a smaller width than the gaps **631**. Since the third domain **750** does not sufficiently expand toward the bottom surface of the gap **637**, a bottom surface D1 of the third domain **750** may be located adjacent to an entrance of the gap **637**. That is, the bottom surface D1 of the third domain **750** may be located at a higher level than bottom surfaces D2 of the first domains **710**. Accordingly, a bottom portion **771** of the fourth domain **770** surrounding the bottom surface D1 and sidewalls of the third domain **750** may be thicker than bottom portions **731** of the second domain **730**. In exemplary embodiments, the gap **637** may have an insufficient space to accommodate two different domains **750** and **770**. In such a case, a portion of the BCP layer **700** filling the gap **637** may not be phase-separated even though the BCP layer **700** is annealed.

The phase separation of the BCP layer **700** may be achieved by annealing the BCP layer **700** at a temperature exceeding a glass transition temperature Tg of the BCP layer **700** to rearrange the polymer blocks of the BCP layer **700**. For example, to rearrange the polymer blocks of the BCP layer **700**, the BCP layer **700** may be annealed at a temperature ranging from about 100 to about 190 degrees Celsius for a time ranging from about six minutes to about twenty four hours.

FIG. **10** illustrates a step of forming a plurality of second openings **701** and a seventh opening **705**.

Referring to FIGS. **6** to **10**, the first domains **710** may be selectively removed to form the plurality of second openings **701** located between the pillars **530**. While the first domains **710** are selectively removed, the third domain **750** may also be removed to form the seventh opening **705** in the first opening trench portion **570**. In such a case, the seventh opening **705** may be shallower than the second openings **701**.

FIG. **11** illustrates a step of forming second extensions **701**B of the second openings **701**.

Referring to FIGS. **6** to **11**, the bottom portions **731** of the second domain **730** exposed by the second openings **701** may be selectively removed to form first extensions **701**A of the second openings **701** extending from the second openings **701**. While the bottom portions **731** of the second domain **730** are selectively removed, the bottom portion **771** of the fourth domain **770** exposed by the seventh opening **705** may be partially removed to form an extension **705**B of the seventh opening **705**. However, the extension **705**B of the seventh opening **705** may be formed not to penetrate the bottom portion **771** of the fourth domain **770**. As a result, a feature of the seventh opening **705** may not be transferred into the bottom portion **771** of the fourth domain **770**.

Subsequently, the first extensions **601**A of the separation wall layer **600** exposed by the first extensions **701**A of the second openings **701** may be selectively removed to form the second extensions **701**B of the second openings **701** extending from the second openings **701**. While the first extensions **601**A of the separation wall layer **600** are selectively removed, the second extensions **603**A of the separation wall layer **600** covering the top surfaces of the pillars **530** and the template portion **590** may also be removed to expose the top surfaces of the pillars **530** and the template portion **590**.

FIG. **12** illustrates a step of forming a blocking pattern **848**.

Referring to FIGS. **4** to **12**, the blocking pattern **848** may cover the first isolated pattern **580**. Before the blocking pattern **848** is formed, residues of the BCP layer **700** including the second domain **730** and the fourth domain **770** may be removed. After the residues of the BCP layer **700** are removed, a sacrificial layer **810** may be formed on the pillars **530**, the first isolated pattern **580** and the template portion **590** to fill the second extensions **701**B of the second openings **701**, the gaps between the pillars **530**, and the gap between the first isolated pattern **580** and the template portion **590**. The blocking pattern **848** may extend to cover the second separation wall portions **602**B adjacent to the first isolated pattern **580**. The blocking pattern **848** may be formed by transferring a layout feature of the blocking pattern **848**. The blocking pattern **848** may cover all of the first isolated pattern **580**, the second separation wall portions **602**B and the third extensions **601**B. However, in exemplary embodiments, the blocking pattern **848** may be laterally shifted from an expected position due to an overlay shift during an alignment and exposure process. Even though the blocking pattern **848** is laterally shifted, the first isolated pattern **580** may still be sealed with the second separation wall portions **602**B and the blocking pattern **848** as far as the first isolated pattern **580** is laterally shifted within an allowable overlay range since the second separation wall portions **602**B and the blocking pattern **848** are disposed around the first isolated pattern **580**.

FIG. **13** is a cross-sectional view illustrating a blocking pattern **848**A which is laterally shifted.

Referring to FIGS. **6** to **13**, in the event that the blocking pattern **848**A is laterally shifted by "S", the blocking pattern **848**A may cover a portion of the template portion **590**. Nevertheless, the blocking pattern **848**A may have an alignment margin of about "R**2**" corresponding to a width of the first opening trench portion **570**. That is, even though the blocking pattern **848**A is shifted so that an edge of the blocking pattern **848**A is disposed in the first opening trench portion **570**, the first isolated pattern **580** may still be sealed with the second separation wall portions **602**B and the third extensions **601**B.

FIG. **14** illustrates a step of selectively removing the pillars **530** and the template portion **590**.

Referring to FIGS. **6** to **14**, the pillars **530** and the template portion **590** may be selectively etched and removed using the planarized sacrificial layer **810**, the first and second separation wall portions **602**A and **602**B, the first and third extensions **601**A and **6018**, and the blocking pattern **848** as etch masks. The pillars **530** may be removed to form third openings **633**, and the template portion **590** may be removed to form a fourth opening **639**.

FIG. **15** illustrates a step of removing the blocking pattern **848**.

Referring to FIGS. **14** and **15**, the blocking pattern **848** and the planarized sacrificial layer **810** may be selectively removed to expose the second extensions **701**B of the second openings **701** extending from the second openings **701**.

FIG. **16** illustrates a step of forming fifth openings **402** and a sixth opening **439**.

Referring to FIGS. **6** to **16**, the underlying layer **400** on the first region **131** may be etched using the first separation wall portions **602**A and the first extensions **601**A as etch masks, thereby forming the fifth openings **402** that extend from the second extensions **701**B of the second openings **701** and extend from the third openings **633**. While the fifth openings **402** are formed, the underlying layer **400** may be patterned to include a first pattern **410** that provides the fifth openings **402**. In addition, the underlying layer **400** on the second region **139** may be etched using the first isolated pattern **580**, and the second separation wall portion **602**B and the third extension **601**B as etch masks, thereby forming the sixth opening **439** that extends from the fourth opening **639**. Accordingly, the underlying layer **400** may be patterned to include a second pattern **418** that provides the sixth opening **439**. The second pattern **418** may correspond to the second isolated pattern. The fifth openings **402** and the sixth opening **439** may be simultaneously formed.

FIGS. **17** and **18** illustrate a step of forming extensions **202** of the fifth openings **402** and an extension **239** of the sixth opening **439**.

Referring to FIGS. **17** and **18**, the second etch target layer **300** and the first etch target layer **200** may be etched using the first pattern **410** and the second isolated pattern **418** as etch masks, thereby forming the extensions **202** of the fifth openings **402** and the extension **239** of the sixth opening **439** that penetrate the first and second etch target layers **200** and **300**. As a result, a second pattern **318** of the second etch target layer **300** and a second pattern **218** of the first etch target layer **200** may be provided by the extension **239** of the sixth opening **439** on the second region **139**, and a first pattern **310** of the second etch target layer **300** and a first pattern **210** of the first etch target layer **200** may be provided by the extensions **202** of the fifth opening **402** on the first region **131**. Subsequently, the first pattern **410** of the underlying layer **400**, the second isolated pattern **418**, and the first and second patterns **310** and **318** of the second etch target layer **300** may be removed to leave the second pattern **218** having a planar shape of the second isolated pattern **418** and the first pattern **210** providing the extensions **202** of the fifth opening **402**.

FIGS. **19** to **22** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to another embodiment.

Referring to FIG. **19**, a layout **2011** may include an array of first target features **2015** which are to be transferred onto the substrate to form patterns. The first target features **2015** may form fifth openings that penetrate a material layer disposed on the substrate. The first target features **2015** may be regularly and repeatedly arrayed to have a certain pitch, for example a first pitch P**1**. The first target features **2015** may include pillar features **2012** arrayed in a diagonal direction and first domain features **2014** disposed between the pillar features **2012**.

Referring to FIGS. **19** and **20**, a layout **2019** may include an array of second target features **2018**. The layout **2011** of the first target features **2015** shown in FIG. **19** and the layout **2019** of the second target features **2018** shown in FIG. **20** may be located at two different regions. For example, the layout **2011** and the layout **2019** may be adjacent to each other. The second target features **2018** may provide sixth openings that penetrate a material layer disposed on the substrate. Each of the second target features **2018** may have a size which is the same as or different from a size of each of the first target features **2015**. While the first target features **2015** are arrayed to have the first pitch P**1**, the second target features **2018** may be arrayed to have a second pitch P**2**. The second pitch P**2** may be greater than the first pitch P**1**. For example, the second pitch P**2** may be twice or more of the first pitch P**1**.

Referring to FIGS. **19** to **21**, a layout **2021** may be obtained by separating the pillar features **2012** from the layout **2011** of the first target features **2015**. That is, the layout **2021** may include pillar features **2022** corresponding to the pillar features **2012** without first domain features **2024** corresponding to the first domain features **2014**.

Referring to FIGS. **20** to **22**, a layout **2029** may correspond to a layout of first opening features **2028** obtained by resizing the second target features **2018**. Each of the first opening features **2028** may provide a space in which a third domain **2078** is induced. As a result, the second target features **2018** may be located at the positions of the third domains **2078**, respectively.

FIGS. **23** to **50** are cross-sectional views and plan views illustrating a method of forming patterns according to another embodiment.

FIGS. **23** and **24** illustrate a step of forming mask patterns **2622** and **2627** on a guide layer **2500**. FIG. **23** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **24** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **21** to **24**, a semiconductor substrate **2100** may have a first region **2121** and a second region **2129** that are distinct from each other, and the guide layer **2500** may be formed by sequentially stacking a SOC layer **2501** and a capping layer **2503** on an entire surface of the semiconductor substrate **2100**. The capping layer **2503** may be formed of a silicon oxynitride (SiON) layer. The pillar features **2022** of the layout **2021** may be transferred onto the semiconductor substrate **2100** to realize the first mask patterns **2622** providing openings **2623** on the first region **2121**, and the first opening features **2028** of the layout **2029** may be transferred onto the semiconductor substrate **2100** to realize the second mask patterns **2627** providing openings **2628** on the second region **2129**. The first and second mask patterns **2622** and **2627** may include a photoresist material.

The guide layer **2500** may be patterned in a subsequent process to form guide patterns that define positions of domains in a phase-separated BCP layer. The guide layer **2500** may be formed on an underlying layer **2400** and may include an SOC layer having a thickness ranging from about 700 to about 800 angstroms. A capping layer (not shown) may be additionally formed on the SOC layer. The capping layer may be formed of a silicon oxynitride (SiON) layer having a thickness of about 300 angstroms.

The underlying layer **2400** may be used to pattern a portion or an entire hard mask in a subsequent patterning process. For example, the underlying layer **2400** may serve as one of multi-layers in a hard mask system. A second etch target layer **2300** may be formed between the underlying layer **2400** and the semiconductor substrate **2100**. In addition, a first etch target layer **2200** may be formed between the second etch target layer **2300** and the semiconductor substrate **2100**. The first or second etch target layer **2200** or **2300** may be one of the hard mask system, or may be selectively etched using the hard mask system as an etch mask in a subsequent process.

The first etch target layer **2200** may be formed of an interlayer insulation layer including a silicon oxide layer such as a tetra-ethyl-ortho-silicate (TEOS) layer having a thickness of about 2200 angstroms. Alternatively, the first etch target layer **2200** may be formed of a conductive layer such as a doped polysilicon layer. The second etch target layer **2300** may be formed by depositing an amorphous SOC layer having a thickness ranging from about 730 to about 1000 angstroms on the first etch target layer **2200**. The underlying layer **2400** may be formed on the second etch target layer **2300** and may include a silicon oxynitride (SiON) layer having a thickness ranging from about 300 to about 350 angstroms.

FIGS. **25** and **26** illustrate a step of forming an array of pillars **2530** and a template portion **2570**. FIG. **25** is a cross-sectional view taken along a line C**21**-C**21'** of FIG. **21**, and FIG. **26** is a cross-sectional view taken along a line C**22**-C**22'** of FIG. **22**.

Referring to FIGS. **21** to **26**, the guide layer **2500** may be etched using the mask patterns **2622** and **2627** as etch masks, thereby forming the array of the pillars **2530** having the same shape as the pillar features **2022** and the template portion **2570** providing first openings **2578** having the same shape as the first opening features **2028**. The array of the pillars **2530** may be formed on the first region **2121** of the semiconductor substrate **2100**, and the template portion **2570** may be formed on the second region **2129** of the semiconductor substrate **2100**.

The pillars **2530** may be arrayed so that four adjacent pillars **2530** are positioned to form a rectangle shape. Alternatively, the pillars **2530** may be arrayed so that three adjacent pillars **2530** are positioned to form a triangular shape. The pillars **2530** may be arrayed to have a gap **2533** between two adjacent ones of the pillars **2530** which are disposed on a diagonal portion of the line C**21**-C**21'**. As illustrated in FIG. **21**, a gap between two adjacent pillar features **2022** which are arrayed on a horizontal line may be narrower than the gap between two adjacent pillar features **2022** which are arrayed on the diagonal portion of the line C**21**-C**21'**. The pillars **2530** may serve as guide patterns that induce self-assembly of the BCP layer which is formed in a subsequent process.

The first openings **2578** in the template portion **2570** may have a pitch which is greater than a pitch of the pillars **2530**. The template portion **2570** may also serve as a guide pattern that induces self-assembly of the BCP layer which is formed in a subsequent process.

FIGS. **27** and **28** illustrate a step of forming a separation wall layer **2600**. FIG. **27** is a cross-sectional view taken along a line C**21**-C**21'** of FIG. **21**, and FIG. **28** is a cross-sectional view taken along a line C**22**-C**22'** of FIG. **22**.

Referring to FIGS. **25** to **28**, the separation wall layer **2600** may cover sidewalls of the pillars **2530**, and sidewalls of the first openings **2578**. The separation wall layer **2600** may include first separation wall portions **2602**A covering sidewalls of the pillars **2530**, a first extension **2601**A extending from the first separation wall portions **2602**A to cover a portion of the underlying layer **2400** exposed by the gaps **2533**, and second extensions **2603**A extending from the first separation wall portions **2602**A to cover top surfaces of the pillars **2530**. The separation wall layer **2600** may further include second separation wall portions **2602**B covering sidewalls of the first openings **2578**, third extensions **2601**B extending from the second separation wall portions **2602**B to cover portions of the underlying layer **2400** exposed by the first openings **2578**, and a fourth extension **2603**B extending from the second separation wall portions **2602**B to cover a top surface of the template portion **2570**.

The separation wall layer **2600** may provide recessed regions defined by gaps **2631** between the pillars **2530** and recessed regions defined by gaps **2637** in the first openings **2578**. The separation wall layer **2600** may be formed of an insulation layer having an etch selectivity with respect to the pillars **2530** and the underlying layer **2400**. For example, the separation wall layer **2600** may be formed of an ultra-low temperature oxide (ULTO) layer having a thickness of about 200 angstroms.

FIGS. **29** and **30** illustrate a step of forming the BCP layer **2700**. FIG. **29** is a cross-sectional view taken along a line C**21**-C**21'** of FIG. **21**, and FIG. **30** is a cross-sectional view taken along a line C**22**-C**22'** of FIG. **22**.

Referring to FIGS. **29** and **30**, the BCP layer **2700** may be formed on the separation wall layer **2600** to fill the gaps **2631** and **2637** which are provided by the pillars **2530** and the template portion **2570**. The BCP layer **2700** may include a polystyrene-poly(meta methyl acrylate) block copolymer (PS-b-PMMA) material or a polystyrene-poly(di methyl siloxane) (PS-PDMS) block copolymer material. When the BCP layer **2700** is formed of the PS-b-PMMA material including PS blocks and PMMA blocks, a volume ratio of the PS blocks to the PMMA blocks may be controlled to be within the range from about 7:3 to about 5:5. The volume ratio of the PS blocks to the PMMA blocks or molecular weights of the PS block and the PMMA block may be appropriately controlled according to a process scheme. For example, the PS-b-PMMA material may have a PS block content of about 60 vol. % to about 80 vol. % and a PMMA block content of about 20 vol. % to about 40 vol. %.

FIGS. **31** and **32** illustrate a step of phase-separating the BCP layer **2700**. FIG. **31** is a cross-sectional view taken along a line C**21**-C**21'** of FIG. **21**, and FIG. **32** is a cross-sectional view taken along a line C**22**-C**22'** of FIG. **22**.

Referring to FIGS. **26** to **32**, the BCP layer **2700** may be phase-separated through an annealing process into first domains **2710** respectively located at central portions of the gaps **2631** between the pillars **2530** arrayed on the line C**21**-C**21'**, and a second domain **2730** disposed between the pillars **2530** to surround the first domains **2710** and to isolate the first domains **2710** from each other. The first domains **2710** may fill recessed regions provided by the second domain **2730**. Thus, the first domains **2710** may have post shapes and may be surrounded by the second domain **2730**.

When the BCP layer **2700** is phase-separated through an annealing process, portions of the BCP layer **700** filling the gaps **2637** provided by the separation wall layer **2600** on the second region **2129** may be phase-separated into third domains **2750** located at central portions of the gaps **2637** and fourth domains **2770** surrounding the third domain **2750** in the gap **2637**. The third domains **2750** may be respectively located at the central portions of the gaps **2637**, and the fourth domains **2770** may cover sidewalls of the first openings **2578**.

The phase separation of the BCP layer **2700** may be achieved by annealing the BCP layer **2700** at a temperature exceeding a glass transition temperature Tg of the BCP layer **2700** to rearrange the polymer blocks of the BCP layer **2700**. For example, the BCP layer **2700** may be annealed at a temperature ranging from about 100 to about 190 degrees Celsius for a time ranging from about six minutes to about twenty four hours to rearrange the polymer blocks of the BCP layer **2700**.

FIGS. **33** and **34** illustrate a step of forming a plurality of second openings **2701** and a plurality of third openings **2705**. FIG. **33** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **34** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **26** to **34**, the first domains **2710** may be selectively removed to form the plurality of second openings **2701** located between the pillars **2530**. When the first domains **2710** are selectively removed, the third domain **2750** may also be removed to form the third openings **2705** in the first openings **2578**.

FIGS. **35** and **36** illustrate a step of forming first extensions **2701**A of the second openings **2701** and first extensions **2705**A of the third openings **2705**. FIG. **35** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **36** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **35** and **36**, bottom portions **2731** of the second domains **2730** exposed by the second openings **2701** may be selectively removed to form the first extensions **2701**A of the second openings **2701** extending from the second openings **2701**. When the bottom portions **2731** of the second domains **2730** are selectively removed, bottom portions **2771** of the fourth domains **2770** exposed by the third opening **2705** may be also removed to form the first extensions **2705**A of the third openings **2705**.

FIGS. **37** and **38** illustrate a step of forming second extensions **2701**B of the second openings **2701** and second extensions **2705**B of the third openings **2705**. FIG. **37** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **38** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **27** to **38**, the first extensions **2601**A of the separation wall layer **2600** exposed by the first extensions **2701**A of the second openings **2701** may be selectively removed to form the second extensions **2701**B of the second openings **2701** extending from the second openings **2701**. When the first extensions **2601**A of the separation wall layer **2600** are selectively removed, the third extensions **2601**B of the separation wall layer **2600** may also be removed to form the second extensions **2705**B of the third openings **2705**. When the first extensions **2601**A and the third extensions **2601**B of the separation wall layer **2600** are selectively removed, the second and fourth extensions **2603**A and **2603**B of the separation wall layer **2600** may also be removed to expose the top surfaces of the pillars **2530** and the template portion **2570**.

FIGS. **39** and **40** illustrate a step of forming a blocking pattern **2827**. FIG. **39** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **40** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **39** and **40**, the blocking pattern **2827** may cover the template portion **2570** and the second extensions **2705**B of the third openings **2705**. The blocking pattern **2827** may correspond to a mask that opens the first region **2121** on which the pillars **2530** are arrayed and covers the second region **2129** on which the template portion **2570** is disposed. Before the blocking pattern **2827** is formed, residues of the BCP layer **2700** including the second domains **2730** and the fourth domains **2770** may be removed. After the residues of the BCP layer **2700** are removed, a sacrificial layer **2810** may be formed on the pillars **2530** and the template portion **2570** to fill the second extensions **2701**B of the second openings **2701** and the second extensions **2705**B of the third openings **2705**. Subsequently, the sacrificial layer **2810** may be patterned to form the blocking pattern **2827** on the second region **2129** as well as a planarized sacrificial layer **2810** on the first region **2121**. In some other embodiments, the blocking pattern **2827** may be formed of a different material from the planarized sacrificial layer **2810** after the planarized sacrificial layer **2810** is formed. In such a case, the blocking pattern **2827** may include a photoresist material, and the planarized sacrificial layer **2810** may include a bottom antireflective coating (BARC) material. In exemplary embodiments, the blocking pattern **2827** and the planarized sacrificial layer **2810** may be formed of two different dielectric layers having an etch selectivity with each other.

FIGS. **41** and **42** illustrate a step of exposing the top surfaces of the pillars **2530**. FIG. **41** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **42** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **41** and **42**, the planarized sacrificial layer **2810** exposed by the blocking pattern **2827** may be partially etched to expose the top surfaces of the pillars **2530**. Subsequently, capping patterns **2503** on the pillars **2530** may be removed to expose the pillars **2530**.

FIGS. **43** and **44** illustrate a step of removing the pillars **2530**. FIG. **43** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **44** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **43** and **44**, the pillars **2530** may be selectively etched and removed using the planarized sacrificial layer **2810**, the first separation wall portions **2602**A, the first extensions **2601**A, and the blocking pattern **2827** as etch mask. The pillars **2530** may be removed to form fourth openings **2703**. Subsequently, the blocking pattern **2827** and the planarized sacrificial layer **2810** may be selectively removed.

FIGS. **45** and **46** illustrate a step of forming fifth openings **2415** and sixth openings **2418**. FIG. **45** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **46** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **45** and **46**, the underlying layer **2400** on the first region **2121** may be etched using the first separation wall portions **2602**A and the first extensions **2601**A as etch masks, thereby forming the fifth openings **2415** that extend from the second extensions **2701**B of the second openings **701** and extend from the fourth openings **2703**. The underlying layer **2400** may be patterned to include a first pattern **2410** that provides the fifth openings **2415**.

In addition, the underlying layer **2400** on the second region **2129** may be etched using the template portion **2570**, the second separation wall portion **2602**B and the third extension **2601**B as etch masks, thereby forming the sixth openings **2418** that extend from the second extensions **2705**B of the third openings **2705**. Accordingly, the underlying layer **2400** may be patterned to include a second pattern **2480** that provides the sixth openings **2418**. The fifth openings **2415** and the sixth opening **2418** may be simultaneously formed.

FIGS. **47** and **48** illustrate a step of forming extensions **2215** of the fifth openings **2415** and extensions **2218** of the sixth openings **2418**. FIG. **47** is a cross-sectional view taken along a line C**21**-C**21**' of FIG. **21**, and FIG. **48** is a cross-sectional view taken along a line C**22**-C**22**' of FIG. **22**.

Referring to FIGS. **19** to **48**, the second etch target layer **2300** and the first etch target layer **2200** may be etched using the first pattern **2410** and the second pattern **2480** as etch masks, thereby forming the extensions **2215** of the fifth openings **2415** and the extensions **2218** of the sixth openings **2418** that penetrate the first and second etch target layers **2200** and **2300**. As a result, a first pattern **2320** of the second etch target layer **2300** and a first pattern **2220** of the first etch target layer **2200** may be provided by the extensions **2215** of the fifth openings **2415** on the first region **2121**, and a second pattern **2380** of the second etch target layer **2300** and a second pattern **2280** of the first etch target layer **2200** may be provided by the extensions **2218** of the sixth openings **2418** on the second region **2129**. Accordingly, each of the extensions **2215** of the fifth openings **2415** may penetrate the first and second etch target layers **2200** and **2300** and have the same shape as the first target feature **2015**, and each of the extensions **2218** of the sixth openings **2418** may penetrate the first and second etch target layers **2200** and **2300** and have the same shape as the second target feature **2018**.

FIGS. **49** and **50** are plan views illustrating a process for obtaining a layout of a guide pattern used in a method of forming patterns according to still another embodiment.

Referring to FIGS. **20** to **50**, a layout **3019** may be set to include an array of third target features **3018**. While the second target features **2018** are regularly arrayed, the third target features **3018** may be irregularly arrayed. A layout **3029** of FIG. **50** may correspond to a layout of first opening features **3028** that are obtained by resizing the third target features **3018** of FIG. **49**. Each of the first opening features **3028** may provide a space in which a third domain **3078** is induced. As a result, the third target features **3018** may be located at the positions of the third domains **3078**, respectively. The method of forming patterns described with reference to FIGS. **23** to **48** may also be used in realization of the third target features **3018** which are irregularly arrayed.

According to the embodiments described above, nano-scale structures or nano structures can be fabricated on a large-sized substrate through a phase separation technique of a BCP layer. The nano-scale structures may be used in fabrication of polarizing plates or in formation of reflective lens of reflective liquid crystal display (LCD) units. The nano structures may also be used in fabrication of separate polarizing plates as well as in formation of polarizing parts including display panels. For example, the nano structures may be used in fabrication of array substrates including thin film transistors or in processes for directly forming the polarizing parts on color filter substrates. Furthermore, the nano structures may be used in molding processes for fabricating nanowire transistors or memories, molding processes for fabricating electronic/electric components such as nano-scaled interconnections, molding process for fabricating catalysts of solar cells and fuel cells, molding process for fabricating etch masks and organic light emitting diodes (OLEDs), and molding process for fabricating gas sensors.

The methods according to the aforementioned embodiments and structures formed thereby may be used in fabrication of integrated circuit (IC) chips. The IC chips may be supplied to users in a raw wafer form, in a bare die form or in a package form. The IC chips may also be supplied in a single package form or in a multi-chip package form. The IC chips may be integrated in intermediate products such as mother boards or end products to constitute signal processing devices. The end products may include toys, low end application products, or high end application products such as computers. For example, the end products may include display units, keyboards, or central processing units (CPUs).

The embodiments of the present disclosure have been disclosed above for illustrative purposes. Those skilled in the art will appreciate that various modifications, additions, and substitutions are possible, without departing from the scope and spirit of the present disclosure as disclosed in the accompanying claims.

What is claimed is:

1. A method of forming patterns, the method comprising:
- forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer;
- forming a separation wall layer including first separation wall portions surrounding sidewalls of the pillars, and forming second separation wall portions covering sidewalls of the first opening trench portion;
- forming a block copolymer layer on the separation wall layer;
- forming first domains in gaps between the pillars, and forming second domains surrounding and separating the first domains by annealing the block copolymer layer;
- forming second openings by selectively removing the first domains;
- forming third openings between the second openings, and forming a fourth opening adjacent to the first isolated pattern by selectively removing the pillars and the template portion; and
- forming fifth openings, which extend from the second and third openings and penetrate the underlying layer, and forming a sixth opening, which extends from the fourth opening and penetrates the underlying layer.

2. The method of claim **1**,
- wherein the separation wall layer is formed to further include a third extension that covers a bottom surface of the first opening trench portion; and
- wherein the second separation wall portions and the third extension have a concave shape.

3. The method of claim **1**, wherein the separation wall layer is formed to further include a first extension that extends from the first separation wall portions to cover a portion of the underlying layer adjacent to the pillars.

4. The method of claim **3**, wherein the second domains are formed to cover the first separation wall portions and the first extension, and to have concave shapes surrounding sidewalls and bottom surfaces of the first domains.

5. The method of claim **3**, wherein the forming of the fifth openings includes:
- forming first extensions of the second openings by selectively removing bottom portions of the second domain exposed by the second openings; and
- forming second extensions of the second openings by selectively removing portions of the first extension of the separation wall layer exposed by the first extensions of the second openings.

6. The method of claim **5**, wherein the forming of the fifth openings further includes selectively etching portions of the underlying layer exposed by the second extensions of the second openings using the first extensions of the separation wall layer as etch masks.

7. The method of claim **1**, wherein the forming of the fourth opening includes:
- forming a blocking pattern covering the first isolated pattern; and

selectively etching the template portion using the blocking pattern and the second separation wall portions as etch masks.

8. The method of claim 7, wherein the forming of the sixth opening includes forming a second isolated pattern that remains under the first isolated pattern and the second separation wall portions by selectively removing a portion of the underlying layer exposed by the fourth opening using the first isolated pattern and the second separation wall portions as etch masks.

9. The method of claim 8, wherein the blocking pattern is formed to have the same shape as the second isolated pattern.

10. The method of claim 7, wherein the forming of the fourth opening further includes before the forming of the blocking pattern:

removing the first domains; and

forming a sacrificial layer that fills the second openings, gaps between the pillars, and a gap between the template portion and the first isolated pattern.

11. The method of claim 8, wherein the blocking pattern is formed to extend onto portions of the second separation wall portions adjacent to the first isolated pattern.

12. The method of claim 11, wherein the blocking pattern is formed to extend onto a portion of the template portion adjacent to the second separation wall portions.

13. The method of claim 1, wherein the forming of the template portion and the array of the pillars includes:

obtaining a layout of the fifth openings and a layout of second isolated pattern whose outline is provided by the sixth opening;

forming a layout of the pillars by separating a layout of the first domains from the layout of the fifth openings;

obtaining a layout of the first isolated pattern and a layout of the first opening trench portion by resizing the second isolated pattern; and

forming the pillars and the template portion using the layout of the pillars and the layout of the first isolated pattern.

14. The method of claim 1, wherein the pillars are formed to serve as guide patterns that induce each of the first domains to a central portion of four adjacent pillars.

15. The method of claim 1, wherein the pillars are formed to serve as guide patterns that induce each of the first domains to a central portion of three adjacent pillars.

16. The method of claim 1,

wherein the forming of the first and second domains includes phase-separating the block copolymer layer into first polymer blocks and second polymer blocks by the annealing of the block copolymer layer, and

wherein the first polymer blocks are ordered to form the first domains, and the second polymer blocks are ordered to form the second domains during the annealing of the block copolymer layer.

17. The method of claim 16, wherein the block copolymer layer includes a polystyrene-poly (meta methyl acrylate) block copolymer (PS-b-PMMA) material.

18. A method of forming patterns, the method comprising:

forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer;

forming a separation wall layer that covers the pillars, the first isolated pattern and the template portion;

forming a block copolymer layer that fills gaps between the pillars, and fills a gap between the first isolated pattern and the template portion;

forming first domains in the gaps between the pillars, forming second domains surrounding and separating the first domains, forming a third domain in the first opening trench portion, and forming a fourth domain surrounding the third domain, by annealing the block copolymer layer, wherein the third domain is shallower than the first domains and a bottom portion of the fourth domain is thicker than bottom portions of the second domains;

forming second openings by removing the first domains, and forming a seventh opening by removing the third domain;

forming first extensions of the second openings, which penetrate the bottom portions of the second domains, and an extension of the seventh opening in the fourth domain without penetration of the bottom portion of the fourth domain, by etching the second and fourth domains;

forming second extensions of the second openings, and exposing top surfaces of the pillars, a top surface of the first isolated pattern and a top surface of the template portion, by selectively removing portions of the separation wall layer exposed by the first extensions of the second openings;

forming third openings by selectively removing the pillars, and forming a fourth opening by selectively removing the template portion; and

forming fifth openings that penetrate the underlying layer and extend from the second and third openings, and forming a sixth opening that penetrates the underlying layer and extends from the fourth opening.

19. The method of claim 18, wherein a width of the first opening trench portion is less than a width of gaps between the pillars so that the bottom portion of the fourth domain is thicker than the bottom portions of the second domain.

20. A method of forming patterns, the method comprising:

forming a template portion to provide a first opening trench portion surrounding a first isolated pattern, and forming an array of pillars on an underlying layer;

forming a separation wall layer that covers the pillars, the first isolated pattern and the template portion;

forming a block copolymer layer that fills gaps between the pillars, and fills a gap between the first isolated pattern and the template portion;

forming first domains in the gaps between the pillars, forming second domains surrounding and separating the first domains, forming a third domain in the first opening trench portion, and forming a fourth domain surrounding the third domain, by annealing the block copolymer layer, wherein the third domain is shallower than the first domains and a bottom portion of the fourth domain is thicker than bottom portions of the second domains;

forming second openings by removing the first domains, and forming a seventh opening by removing the third domain;

forming first extensions of the second openings, which penetrate the bottom portions of the second domains, and an extension of the seventh opening in the fourth domain without penetration of the bottom portion of the fourth domain, by etching the second and fourth domains;

forming second extensions of the second openings, and exposing top surfaces of the pillars, a top surface of the first isolated pattern and a top surface of the template portion, by selectively removing portions of the separation wall layer exposed by the first extensions of the second openings;

forming a blocking pattern that covers the first isolated pattern and a portion of the template portion adjacent to the first isolated pattern;

forming third openings by selectively removing the pillars using the blocking pattern as an etch mask, and forming a fourth opening by selectively removing the template portion; and

forming fifth openings that penetrate the underlying layer and extend from the second and third openings, and forming a sixth opening that penetrates the underlying layer and extends from the fourth opening.

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